THE DESIGN OF A SEMI-AUTOMATED LUNAR BRICK MAKING MACHINE

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ABSTRACT

The process developed last quarter was implemented by a single, portable machine. Water and the binder, lignin sulfonate, are stored in the machine. Lunar fines are brought into the machine by a screw type conveyor. The fines are then dumped into a sealed mixing chamber with the water and lignin in the proper stoichiometric amounts. In the mixing chamber, the sludge is thoroughly mixed with a device similar in design to a manual eggbeater. The sludge then flows into the mold, and the mold chamber is sealed. A pump pulls a hard vacuum on the chamber, thereby drying out the brick and activating the lignin bond. The water from the brick is reclaimed by increasing the pressure on the ambient atmosphere in the chamber, which has been chosen to be Nitrogen. The collected water flows back into a holding tank for the mixing chamber, the brick is removed from the mold chamber, all chambers are resealed, and the process is repeated.

PROBLEM STATEMENT

Background

One of the most formidable projects ahead of the American space program in the late 20th and early 21st centuries will be the establishment of a permanent base on the moon. As the freight cost for shipping building materials to the moon is prohibitive, the best solution in manufacturing permanent structures on the lunar surface must involve the use of the moon's own resources.

A process has been developed that requires only a small amount of binder and water from the Earth, added to raw lunar soil, to manufacture bricks. There still exists a need, however, for a device to implement this process. If such a machine were built and put into operation, a permanent moonbase would be well on its way to becoming a reality.

Constraints

The machine that is designed must meet several stringent criteria. First, the device must be able to operate in a lunar environment, which involves radical shifts in temperature, as well as a harsh vacuum. Second, a lunar structure must be built within one lunar day if the first moon base astronauts are to survive the lunar night. This means that the bricks must be made and assembled into a structure within 13 Earth days. To allow ample time for construction, the 960 bricks required to construct one building should be produced in less than 5 days. This gives a rate of approximately one brick every 7.5 minutes, assuming brick dimensions of 1 foot by 1 foot by 1.5 feet. Next, the system should reclaim nearly 100% of the water used in the process to eliminate the necessity of importing more from the Earth. Further, the machine should be automated, requiring only the occasional supervision of a single operator. This would enable the astonauts to conduct other experiments or concentrate on the actual construction of the structure. Finally, the machine should be portable. If the bricks can only be made at one location, then a special carrier would need to be developed for structures that are separated by a great distance. It is cheaper just to make the brick machine mobile so that bricks can be produced as long as lignin and water are available.

PROCESS OUTLINE

The brick making system should consist of the following subsystems:

1. Screw Conveyor
2. Mixing Chamber
3. Molding Chamber
4. Water Reclamation System
5. Brick Removal System

Screw Conveyor

The lunar fines necessary for the process will be supplied to the system by a screw conveyor. This conveyor will supply fines at a constant rate to a catch placed above the mixing chamber. This catch will be timed to open after a certain predetermined time period to dispense the precise volume of fines needed by the process. A flap will cut off the flow of fines while the fines are being poured into the mold chamber. This will ensure that the chamber does not receive too many fines for any brick.

Mixing Chamber

The fines will be dispensed into the mixing chamber along with the proper amounts of lignin sulfonate and water. The chamber is sealed off from the lunar environment and contains a low pressure Nitrogen atmosphere. The pressure of the nitrogen serves to keep the water in the liquid state during mixing. The sludge created by the mixture of fines, lignin, and water is then mixed by several spiked shafts that rotate as they precess around the chamber. After the sludge is thoroughly mixed, the bottom of the chamber opens to dispense the contents into the mold.

Molding Chamber

The molding chamber consists of a pressure vessel surrounding the mold. When the mixing chamber opens, the sludge pours into the mold. The chamber then seals once more, leaving the mold chamber with a low pressure Nitrogen atmosphere and a brick containing liquid water. A valve is then opened, and a vacuum pump evacuates the atmosphere in the chamber. The water boils under the low pressure and diffuses out of the brick as vapor, which then flows out of the chamber due to pump action. The mold then releases the brick and reseals.

Water Reclamation System

After the vapor has passed through the pump, it must be condensed for reuse in the mixing process. This is accomplished by pumping the Nitrogen and water vapor into a tank that is a fraction of the size of the mold chamber. This reduction in volume results in a high pressure atmosphere, which forces the water to condense. This water is collected and sent back into the mixing chamber for use as an activator for the lignin once more.

Brick Removal System

When the brick is released by the mold, it drops to the bottom of the mold chamber. As the pressure in the chamber is a hard vacuum, the bottom of the chamber may swing open at no cost to the system. The brick slides down onto either the ground or an external conveyor, depending on the available arrangements, and the bottom swings back into place and reseals. The entire process can then be repeated.

The above processes are not necessarily sequential. The water reclamation should occur while the last brick is being removed and the next brick is being mixed. This sort of scheduling can streamline the process and enable faster production of bricks.

SYSTEM MATERIALS

Atmosphere

To keep the water in its liquid state, even at the process temperature of 77 F, an atmosphere at a finite pressure is required. Nitrogen has been chosen due to its availability and its similarity to normal air. This second property enables the use of standard air and water tables, which proves invaluable to an initial design iteration.

Substance measurements

The following ingredients are mixed together to form the proposed 1 ft by 1 ft by 1.5 ft brick: 1.2 ft of lunar fines, 0.012 ft of lignosulfonate binder, 0.108 ft of water. For a complete structure of 960 bricks, this amounts to 1152 ft of lunar rock, 11.52 ft of binder, and 0.108 ft of water. The entire amount of lignosulfonate and water must be shipped from the earth. Ideally, 100 percent of the water will be reclaimed from the brick after it enters the mold so that the reclaimed water may be reused. A shipment of 0.5 ft is proprosed to cover for any loss.

The lunar soil has an approximate specific gravity of 125 lbs/ft and will require a total of 1152 ft . The lunar fines will be stored in a container and a screw conveyor running into the mixing chamber will transport the 1.2 ft of lunar fines into the mixing chamber. The lunar surface, rated as well graded silty sand to sandy silts and having a cohesiveness of 0.015 psi to 0.15 psi in nature, should produce no problem in transporting or mixing.

As a binder, lignin sulfonate has a density of 78.18 lbs/ft . A total amount of 0.012 ft of binder per brick and 11.52 ft of binder per structure is required. Each brick requires 0.108 ft of water to properly suspend the lignosulfonate in the brick mixture.

Lignosulfonate

In its natural state, lignin is the principal carrier of the methoxyl content of wood. Approximately 25 percent of the wood which goes to the pulp mills is obtained as lignin in one form or another. The sulfite pulp industry has attempted to utilize a minor part of this as road binder, adhesives, and core binder. The method by which the lignin is originally extracted from the wood will affect the structure and the physical properties of the substance.

One of the most important lignin reactions if the sulfonation of lignin in which sulfonate ions attach to the lignin forming lignosulfonate. The substance formed by this method is a light powder. The powder has a bulk density of 11.23 lbs/ft , a tap density of 18.72 lbs/ft , an extremely low vapor pressure, and a high green strength. The powder is highly soluble in water. When mixed with the lunar fines and water, the lignosulfonate is suspended throughout the sludge. When a vacuum is pulled on the mixture to extract the water, the lignosulfonate remains with the soild producing a strong brick composed of 99 volume percent lunar soil and 1 volume percent binder.

The lignosulfonate maintains the desirable properties at a large range of temperatures and thus the process is restricted by the temperature of the water more than the temperature of the lignin. At a temperature of 77 F, the process will take place with no difficulty. The volume of water added to the mixture is 0.108 ft . Too little water will not ensure sufficient spreading of the binder throughout the lunar soil while an overabundance of water may leave the final structure too porous.

Material Acquisition and Handling

The fundamental objective of material acquisition and handling is to provide the raw materials necessary to implement the brick making process. The raw material must not only be provided at a suitable rate, but also it must have specific properties which will determine the success of the process. These properties are density and temperature.

The density of the raw material will determine the permeability, porosity, viscosity, drying rate, and strength properties throughout the process. It was originally thought that an elaborate sifting and crushing process was necessary to provide a suitable density; however, close examination of the lunar surface reveals properties which can greatly simplify this process.

First, the outer layer or regolith of the moon is a "pre-sifted" layer. Material in this layer has a diameter range from 120 micrometers to 3 millimeters. The result of this distribution is an aggrigate free density of 1.17 g/cm^3 and a shaken down density of 1.20 g/cm^3. This density is suitable for the brick making process.

In addition to providing a consistant density, the regolith has another convienient property. The temperature of this layer between 0.15 m amd 1 m varies only 2 degrees Kelvin. Beyond 1 meter, the temperature is a constant 252 degrees Kelvin.

By using the material in the regolith, crushing is eliminated and sifting is reduced to a single stage process. In addition, the heating and cooling requirments are reduced.

Material Acquisition

Several conventional methods for acquisition of the regolith were suggested. All but one were rejected primarily because they did not allow for the containment of the material in the low gravity environment. The remaining method was the screw pump. The primary components of the screw pump are the drive system and the screw.

The drive system consists of:

1. Motor
2. Clutch
3. Transmission

The selection of the motor depends on a number of requirements. It must provide the torque necessary; it must efficiently use the available power; finally, it must weigh as little as possible.

The torque requirments were estimated by those requirments necessary to dig soil on the earth. For a 5" diameter auger bit, drilling to a depth of four feet, the peak torque required is 140 ft*lbs. To achieve this torque directly, the motor must be large. By incorporating a small transmission system, we can use a much smaller motor to get the required touque. A simple transmission which reduces the input torque greatly is the use of a straight bevel gear arrangment in which the gear ratio is 3:1. Such an arrangment reduces the input torque to approximately 50 ft*lbs. With this reduced torque, a much smaller motor may be chosen.

In addition to providing the necessary torque, the motor must use the available power and use it efficiently. The power is assumed to be provided by direct current. A search of available D.C. motors revealed the best type of motor for the lunar screm pump application to be the torque motor. Torque motors provied high torque with low weight and low RPM. Of the available D.C. torque motors, the best that had a 50 ft*lb operating torque needed only .5 HP and weighed only 13.8 lbs.

The drive system of the pump is not yet complete. Because the load on the motor is cyclical and subject to shock, a clutch is necessary to avoid damaging the motor and additionally allows the slow start up RPM required in digging. Clutches divide into the following categories - mechanical contact, electromagnetic flux, and fluid.

Mechanical contact clutches such as the disk and pad assembly were rejected because of the heat they build up and they need parts perodically replaced. Fluid clutches were rejected because they are bulky and have problems with sonic leakage in a vacuum environment.

The remaining category, electromagnetic flux, divides into three parts - eddy current, hysteresis, and magnetic particle. The magnetic particle clutches were rejected because their continuous slip mode creates a great amount of heat. Of the two remaining, the eddy current clutch was chosen because of its lower power consumption. Of the available eddy current clutches, the best 50 ft*lb model consumed 15 HP at peek torque and weighed 42 lbs.

The screw perform two jobs. First, it digs into the ground at the leading edge. Next, it transports the material along the flightings. Because of the dual purpose of the screw, the leading edge must be heliciodal and have sharp flightings. As the material travels up the screw, a shaft must be introduced to prevent bending and cups at the outer edge of the flightings are incorporated to reduce friction at the wall.

The length of the screw with flightings is four feet. This allows the screw to penetrate well into the regolith layer while maintaining a reasonable overall height of the screw pump mechanism. The screw shaft extend through the housing and is supported by two bearings. The bearing loads were calculated as were the loads on the drive shaft bearings. Because the load is a combined thrust and radial load on all the bearings, tapered roller bearings were selected for use. Because the bevel gear arrangment exerts the same thrust regardless of direction of rotation , the drive shaft bearings must be indirectly mounted, and the screw shaft bearings should be directly mounted.

Once the soil has reached the top of the screw, it is compressed into a flexible tube and transported to the siol bin. By using a flexible tube, the screw pump may be moved to various locations around the bin before the bin needs to be moved. Dry material hoses which combine wear resistant rubber with high strength steel seem to be appropriate for this application.

The housing should be constructed of A03330-T6 aluminum alloy casting. This will give the housing suitable strength and lightweight. Also, by casting the housing, the machining necessary to form the motor, clutch, and transmission mounts could be reduced significantly.

The screw pump mechanism is able to supply the necessary 9.7

ft^3/hr by digging one hole every 4.5 minutes. This should allow plenty of time for sight selection and movement of the pump and allow stockpiling in the soil bin.

Material Handling

Once the soil has been pumped through the flexible tube, it is introduced into a cylindrical tube within the soil bin which rotates at approximately 1000 RPM. This has two effects. First, it shears the clumps of soil into fine particles and allows them to pass through the screen. Secondly, the dynamic activity helps to heat the soil. The particles which are an eighth of an inch or larger are carried out the opposite end of the screen tube by a slowly rotating (20 RPM) screw and exit through a drop shute. Any particles which tend to get caught in the screening are forced back out in the cylinder by means of a nylon brush which extends the length of the screen. A deflector is positioned along the axis of the screen to force particles in the preferred outward direction. The screen assembly is powered by a 300 ft*lb D.C. torque motor connected directly to the screen sleeve and a transmission supplies power to the screw.

Once the material is inside the bin, the temperature may be raised by exposing it to sunlight. Once the desired temperature is reached, the soil may be kept within the desired temperature range by periodically exposing it. This may be done by covering the bin with a voltage sensative window which transmits in the infrared when no voltage is applied and is opaque when voltage is applied. t is important to keep the soil at a depth no more than

15 cm when initially heating. The low thermal conductivity of the soil (1.9 kcal/m*hr*deg) does not allow for greater depths to warm.

Finally, the soil if transmitted to the vertical screw by means of a horizontal screw at the base of the soil bin. This screw is driven by the same type of motor as the screen assembly.

TRANSPORT

Screw conveyors are one of the oldest and simplest methods for moving bulk materials and consist primarily of a conveyor screw rotating in a stationary trough. Material placed in the trough is moved along its length by rotation of the screw which is supported by hanger bearings. Inlets, outlets, gates and other accessories control the material and its disposition.

Screw conveyors are compact, easily adapted to congested locations and can be mounted horizontal, vertical, and in inclined configurations. They can also be used to control the flow of material in processing operations which depend upon accurate batching or as a mixer to blend dry ingredients.

Screw feeders are modified screw conveyors used to control the flow of material at a constant or variable rate from hoppers, bins or tanks. They are suitable for handling a wide variety of materials ranging from fines to a combination of fines and lumps. Under many conditions feeders are also used as a valve. These feeders are totally enclosed and compact, simple in design and dust tight.

Conveyor screw with drive shaft

The conveyor screw is the rotating portion of a screw conveyor which imparts smooth and positive motion to the bulk material being transported. It consists of spiral flighting mounted on a pipe and is made either of right or left hand screw to suit the screw rotation and the desired direction of material travel.

The conveyor drive shaft connects the conveyor screw to the driving unit and transmits rotary motion to the screw. Coupling bolts secure the drive shaft in the conveyor screw. Stepped pitch conveyor screws are used as feeder screws for handling friable lumpy material from bins or hoppers and also to draw the material uniformly from the entire length of the feed opening.

The drive shaft also delivers the driving power, and should therefore be carefully designed of high quality steel of the proper characteristics to provide adequate torque, bending and shear strength; and with closely controlled tolerances for correct bearing clearances. The conveyor end shaft supports the last section of the screw and should be furnished with close tolerances for proper operation in end bearing.

Specifications

To facilitate the selection of proper specifications for a screw conveyor for a particular duty, screw conveyors are broken down into three component groups. Because the material to be conveyed is not listed in Table 4, then its classification code may be determined from Table 3. Table 8 is a guide to the proper selection of the appropriate component group. It will be observed that in addition to the flow characteristics of a material, consideration must be given to material size, its abrasiveness and its corrosiveness as these determine construction details.

The material characteristics in Table 4 (See Appendix A) lists a wide range of bulk materials that can be handled in screw conveyors. The table shows in the first column the range of density that can be experienced in handling that material. The "as conveyed" density is not specifically shown but it is assumed to be at or near the minimum.

The next column shows the material code number. This consists of the average density, the usual size designation, the flowability number, and the abrasive number followed by the material charactristics which are termed conveyability hazards. Lunar fines were not listed in Table 4; however, Tables 3 and 4 were used to determine the material code and material factor, Fm, which is used in the horse power formula.

mat'l characteristics		**code designation**
bulk density, loose	125 lbs/ft^3	125
size	fine, 0.132" and under	B6
flowability	assume sluggish	4
abrasiveness	extremely abrasive	7

Therefore, the proper material code and resulting approximation for Fm are the following:

material code	Fm
125B 47 6	2.8

Lump size limitations

The size of a screw conveyor not only depends upon the capacity required, but also on the size and proportion of lumps in the material to be handled. The size of a lump is determined by its maximum dimension. A closer definition of lump size would be the diameter of a ring through which the lump would pass. However if the lump has one dimension much longer than its transverse cross-section, the long dimension would determine the lump size.

The character of the lump is also involved. Some materials have hard lumps that will not break up in transit through a screw conveyor. In that case provisions must be made to handle these lumps. Other materials may have lumps that are fairly hard, but degradable in transit through the screw conveyor which reduces the lump size to be handled. Still other materials have lumps that are easily broken in a screw conveyor and, lumps of these materials impose no limitations.

Three classes of lump sizes apply as follows:

Class 1

A mixture of lumps and fines in which not more than 10% are lumps ranging from maximum size to one half of the maximum; and 90% are lumps smaller than one half of the maximum size.

Class 2

A mixture of lumps and fines in which not more than 25% are lumps ranging from the maximum size to one half of the maximum; and 75% are lumps smaller than one half of the maximum size.

Class 3

A mixture of only lumps in which 95% or more are lumps ranging from maximum size to one half of the maximum; and 5% or less are lumps less than one tenth of the maximum size.

The allowable size of a lump in a screw conveyor is a function of the radial clearance between the outside diameter of the central pipe and the radius of the inside screw trough, as well as the proportion of lumps in the mix. The ratio, R, is defined as follows:

$$R = \frac{\text{Radial Clearance (inches)}}{\text{Lump Size (inches)}}$$

The following illustration shows this relationship.

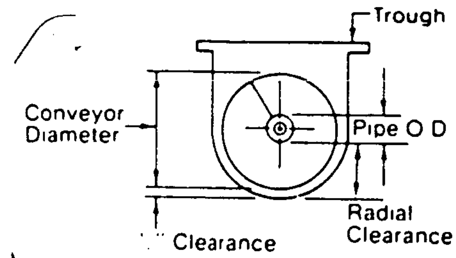


Figure C

From Table 7 the ratio, R, was taken to be 4.5 and the radial clearance (4.5)(.132) or 0.594 inches. Since this value is much less than the lowest radial clearance found on Table 7, the lump size will not be a concern for this application; therefore assume the smallest size screw diameter (6 inches) will suffice.

Capacity table

The capacity table (Table 5) gives the capacities in cubic feet per hour at one revolution per minute for various sized screw conveyors for four cross-sectional loadings and for various classes of materials as delineated by code numbers. Also shown are capacities in cubic feet per hour at the maximum recommended revolutions per minute (rpm).

To input 1.2 cubic feet of lunar fines in 2 minutes as requested by the mixing group translates into a required capacity of 36 cubic feet per hour. For screw conveyors having regular helical flights all of standard standard pitch, the conveyor speed, N, may be calculated by the formula:

$$N = \frac{\text{Req'd capacity (cubic feet per hour)}}{\text{Cubic Feet Per Hour at 1 RPM}}$$

Assume a 15% degree of trough loading , a required capacity of 36 cubic feet per hour and a screw diameter of 6 inches. The number of revolutions per minute of screw is (36)/(0.75) or 48 rpm.

Conveyor screw speeds must be considered when using hard iron bearings on hardened coupling shafts in order to minimize wear and to reduce the squealing noise of dry metal on dry metal. Checking the component group designation (3D) found on Table 8 indicates hard iron will be used in this application. The following formula gives maximum recommended operating speed:

$$N = \frac{120}{\text{Shaft Diameter (inches)}}$$

The maximum operating rpm of the screw is calculated to be (120)/(2) or 60 rpm. The required rpm of 48 is less than the maximum rpm; therefore, no change in design is required.

For hard iron bearings, the shafting for the couplings is usually low carbon steel and surface hardened. Suitably hardened alloy shafting may also be used.

From Table 13, for a component group D , the hanger bearing factor, Fb, is 4.4. The equivalent length of the feeder is calculated from the following equation:

$$L_f = L_1 + B/6 + C/12$$

B and C are obtained from Table 16, and Figure F shows what dimensions B and C refer to on a single screw feeder. L_1 is equal to the length of the feeder, which is chosen to be 7 feet. For a 6 inch diameter screw, B is given as 36 and C is given as 12. The equivalent length ,therefore, is 14 feet.

From Table 14 the conveyor factor, Fd, is given as 18 for a 6 inch diameter screw.

Power required

The calculation of the required horsepower to operate screw feeders involves the addition of two horsepowers, one for the empty feeder friction, and the other for the material friction.

Horsepower for a single screw feeder is as follows:

$$HP = \frac{(HPa + HPb) * Fo}{e}$$

HP_a and HP_b are defined as follows:

$$HPa = \frac{L1\ N\ Fd\ Fb}{1{,}000{,}000} \quad \text{Empty Feeder Friction Power}$$

$$HPb = \frac{C\ W\ Lf\ Fm}{1{,}000{,}000} \quad \text{Feeder Material Friction Power}$$

where

nomenclature	values
C = Capacity in ft3/hr	36
W = Density of material in lbs/ft^3	125
L_f = Equivalent length in ft	14
L_1 = Length of feeder in ft	7
N = Speed of screw rotation in rpm	48
Fb = Hanger bearing factor (Table 13)	4.4
Fd = Conveyor diameter factor (Table 14)	18
Fm = Material factor (Table 4)	2.8
Fo = Overload Factor (figure 14)	
e = efficiency of the drive selected	

Referring to Figure D, the factor Fo depends upon the sum of the horsepower for friction of the empty conveyor (feeder in this case) and the horsepower of material friction. In this example the sum is (.027) + (.176) = .203 HP, and Fo is approximately 3.

Then assuming a slightly less than typical drive efficiency of 75% yields a HP requirement of .81 HP; therefore using a 1 HP motor with speed reduction to 48 rpm would achieve the necessary flow rate.

The theoretical estimated power requirements just calculated could be exceeded to the extent that the full 1 horsepower of the motor would be used. Therefore, all components of the power train, the feeder shaft, the screw pipe shaft, and the screw itself should be capable of withstanding - at the speeds involved for each- the torsion force or torque of a full 1 horsepower. Table 15 lists the torsional capacities of screw conveyor components.

Table 15 combines the various torsional ratings of bolts, couplings and pipes so that it is easy to compare the torsional ratings of all stressed parts of standard conveyor screws. The table conforms to the CEMA Screw Conveyor Standard No. 300. The torsional values are confined to the sizes listed in that standard.

The lowest torsional rating figure for any given size of coupling will be the one that determines how much horsepower may be safely transmitted. The governing equation is as follows:

$$\text{Torque}, T = \frac{63025 \times HP}{N\ (rpm)}$$

The torque developed by a 1 HP motor at a speed of 48 rpm is 1313 in. lbs.. Thus it can be seen that the shaft itself is the limiting factor, and a 1.5 inch shaft diameter is required for this system.

Counter shaft trough ends, as shown in figure X, are recommended to limit the interference with the mixer. Application of countershaft trough ends permits drive installations alongside, above or below the conveyor and permits the use of horizontal drives for inclined conveyors.

A rectangular trough may be made as illustrated in figure Y from a single steel sheet or with sides and bottom of separate pieces, dependent upon size and gauge of metal. It is recommended to handle abrasive materials capable of forming a layer of material on the bottom of the trough. The material thus moves on itself, protecting the trough from undue wear.

No. 226 hangers shown in figure Z have a rigid, formed-steel box frame with clearance for passage of material in large volume. They are mounted within the conveyor trough and are furnished with hard iron bearings.

Table 1 gives all necessary dimensions with the exception of conveyor screw length which can be furnished to suit the required equivalent length of 14 feet. A secondary catch trough will also be required that will facilitate the return of lunar fines to the loading bin as shown in figure 00. This return system is continuous operation of the screw. Thrust forces incurred during start and stop operation would cause unnecessary wear out of the feeder, so the screw will operate continuously.

Volume control

To obtain the required 1.2 cubic feet of lunar fines, a flap valve will be opened to allow the filling of an air lock chamber. As the flow rate of fines is already known, the flap and valve 1B will remain open for 2 minutes and then close. When the flap is closed the fines will simply be returned via the secondary trough back to the bin (See Drawing 6).

The lignin sulfonate is measures out into a pipe that has a volume of .012 cubic feet. Valve 1A is opened to allow the binder to fill the connecting pipe. Then valve 1A is closed and valve 2A is opened and the lignin is emptied into the intermediate chamber and introduced into the mixing chamber with the lunar fines. Introducing the lignin sulfonate along with the lunar fines will help keep the lignin sulfonate from dusting the gears in the mixing chamber.

Once valve 1B has been closed and valve 2A has been closed (i.e. the intermediate chamber is loaded with the fines and binder), valve 2B may be opened to allow the fines and binder to mixing chamber via gravity. Load time should not exceed 1 minute. Valve 2B should close and the chamber will be ready for reloading.

MIXING

The mixing process takes place by combining lunar fines, lignosulfonate, and water in a mixing chamber. The substance is then mixed using revolving shafts with attached spikes. After the mixture is thoroughly stirred, the bottom of the mixing chamber opens and the sludge flows into the mold in the chamber below.

The three ingredients are input into the mixing chamber by two pipes located near the top on the sides of the cylindrical chamber. First, the lignosulfonate and the lunar fines will be dumped into the chamber and their input pipe sealed off with a valve. Next, the water pipe will be opened and the water added to the chamber. The water pipe entrance will then be closed with a valve so that the entire chamber is sealed. The agitators attached to the revolving gears may revolve continuously so that mixing takes place during the addition of the ingredients. Sufficient mixing should be attained in four minutes. Further testing may suggest that a longer or shorter amount of time is actually required for the mixing process to take place. Once completed, the bottom of the mixing chamber will be opened to allow the sludge to flow out into the mold below. The bottom of the mixing chamber will be made of a series of vanes attached to one bar so that when the bar is moved horizontally, the vanes will open and the sludge may exit the mixing chamber. The mixture will then flow through a cone-shaped tube connecting the mixing and mold chambers. This tube is sealed off with a butterfly valve. This valve opens to allow the mixture to flow into the mold and closes to ensure a vacuum-tight chamber for water reclamation. Once the mixing chamber is empty, the bottom of the chamber and the butterfly valve will close and the next batch of ingredients may be added.

Methods of mixing

A system with four gear controlled agitators will be used to mix the substance. This will utilize a central shaft which extends into the mixing chamber to rotate four spur gears. Each of the four gears will have an attached shaft extending from the gear to 0.5 inches above the bottom of the chamber. Each of the four revolving shafts will have five rows of four cylindrical spikes which overlap with adjacent shafts to ensure complete mixing. On shafts located adjacent to each other, the rows will be placed at different vertical positions to prevent contact. On shafts located diametrically across the chamber, the rows will be at the same vertical position but the shafts will be placed so the spikes are at different angles horizontally. This orientation will prevent contact among any of the spikes.

Due to its portability, ease of implementation, and ability to mix, the gear system is well suited for use in the lunar environment. Other methods considered were a mechanical batch mixer as used for clay masonry construction and ultrasound mixing as used for mixing fluids. The mechanical batch mixer was rejected due to the lack of natural damping in the lunar environment. The ultrasound was rejected because it would only serve to agitate the sludge and not mix it. The ultrasound may be useful in shaking the mold for compacting the sludge but this is not necessary.

Mixing chamber

The cylindrical mixing chamber, made of aluminum, is 27 inches high, 15 inches in diameter, and 0.188 inches thick. The chamber will be cylindrical for optimum mixing and minimum stress concentration. The 15 inch diameter will allow the heigth and width of the sludge to be approximately equal. The 27 inch heigth will leave room for the input tubes, gears, and proper spacing from the top of the sludge to the top of the chamber. A thickness of 0.188 inches will adequately hold the stress due to the pressure and support of the system. Aluminum will be used due to its high strength to weight ratio.

The valve that allows the mixture to flow from the mixing chamber to the mold nozzle consists of a series of eight fitted damper vanes. These vanes will span the entire 15 inch diameter. A side view of each vane is a parallelogram with the top and bottom lengths being 1.852 inches and the height being 0.188 inches. This shape allows overlapping which prevents leakage between vanes. The vanes are made of 0.188 inch thick aluminum. The aluminum has a high strength to weight ratio and will adequately support the sludge in the lunar gravity.

The series of vanes will be broken up into two halves to allow the vanes to open properly. The vanes on the left half will be hinged on the right side so they will open towards the bottom. The vanes on the right half will have their hinges on the left so they will also open towards the bottom. Where the two halves meet, the right vane will be rounded on the bottom to prevent interference when opening. This right center vane will have a top length of 1.667 inches to allow proper fit of the vanes across the diameter. The two outside vanes are rounded upward on the top so the vanes may open without interfering with the sides of the mixing chamber. Each of the vanes on the right half will have a crank which comes out parallel to the vane and turns upward. The cranks for the left half will come out parallel and turn downward. The end of each crank will be connected to a single bar which when translated horizontally rotates the vanes to the desired position.

At the bottom of the nozzle is a butterfly valve 6 inches in diameter. This valve controls the flow from the nozzle to the mold. The butterfly valve will completely seal the entrance to the mold chamber so that a vacuum may be maintained. It will also sweep the entrance of the chamber clean when opening and closing. Synchronization of the vanes and the butterfly valve allows full control of the flow of the sludge from the mixing chamber to the mold chamber.

Input tubes

Two input pipes will be used to introduce the lunar fines, lignosulfonate, and water in the mixing chamber. The top of these pipes will be located 4 inches below the top of the mixing chamber. This placement will prevent interference with the gears but will leave clearance space between the bottom of the input tube and the top of the sludge.

A 6 inch diameter, 6.6 inch long pipe entering on one side of the chamber will be used to input water. At the end of the pipe will be a water holding tank containing the extra water shipped to the moon and the reclaimed water obtained from the mold chamber. This stored water will be used if water must be added to fill the 0.108 ft needed. A valve will open and close the pipe at the entrance to the chamber and the exit of the holding tank. The holding tank valve will open and the 0.108 ft pipe will fill with water. This valve will then close and the valve at the mixing chamber will open allowing the 0.108 ft to enter the mixing chamber.

On the other side of the mixing chamber, a 6 inch diameter pipe will be used to input the lunar fines and lignosulfonate binder. This pipe will be y-shaped. One leg will enter into the mixing chamber. One leg will connect to a container of lignosulfonate binder with a valve used to control the flow. The other leg will connect to a screw conveyor transporting the lunar fines. The screw conveyor will regulate the flow of soil into the chamber.

Gears

A central shaft 0.375 inches in diameter enters the chamber through the top center and attaches to the central pinion. As Drawing 3 shows, there are four spur gears evenly spaced around the pinion. The top surface of each of the gears is located 0.5 inches from the inside top of the chamber. The minimum diameter that the central shaft can be with no safety factor is 0.218 inches. A central shaft of 0.375 inches will have a safety factor of 5. (See Appendix B) A standard 0.25 horsepower, 115 volt, 60 hz motor equipped with a gear box to deliver 400 in-lb of torque at 30 rpm will be used to drive the central shaft. This will require 4.6 amps. The motor will be coupled directly to the central shaft of the mixing chamber.

The pinion is 3 inches in diameter, has a pitch of 6 teeth/inch, and has 18 teeth. (See Appendix B) The radius of the dedendum circle is 1.292 inches and the radius of the addendum circle is 1.667 inches. The facewidth of the pinion is 1.662 inches. The four gears are identical and each has a diameter of 4 inches, a pitch of 6 teeth/inch, and 24 teeth. The radius of the dedendum circle is 1.797 inches and the radius of the addendum circle is 2.166 inches. The pressure angle is 20 . The facewidth of each gear is 1.662 inches. These dimensions will give a contact ratio of 1.565 between the gear and the pinion. (See Appendix B) This contact ratio will eliminate the possibility of impact between the teeth. The gears will have a safety factor for fatigue loading of 8.

Agitators

As Drawing 2 shows, each of the four gears has a 0.375 inch shaft attached to it which extends from the top of the mixing chamber to 0.5 inches above the bottom of the chamber. The stirrers will be made of G41400 steel which has a yield strength of 131 kpsi drawn at 1000 degrees F. The minimum diameter that the shafts can be with no safety factor is 0.151 inches. A shaft of 0.375 inches will have a safety factor of 5. (See Appendix B) This high safety factor is desirable due to inconsistencies in the lunar soil which may exert additional forces on the shaft.

Each shaft will be cast with five horizontal rows of spikes. Each row consists of four cylindrical spikes evenly spaced around the shaft. An individual spike is 3.75 inches long measured from the center of the shaft or 3.56 inches measured from the outside diameter of the shaft. This length allows for 0.25 inch clearance between the end of the shaft and the chamber wall. The spike is 0.375 inches in diameter and flat on the end.

The spikes on adjacent shafts must be staggered. The center point of the bottom row of spikes on two opposite shafts will be 0.5 inches from the bottom of their shafts. The remaining four rows on these two shafts will have their center points located 2.8 inches apart. Thus, the center points of these five rows will be placed at 0.5, 3.3, 6.1, 8.9, and 11.7 inches from the bottom of the shaft. The other two opposite shafts will also have rows placed 2.8 inches apart. These rows will be placed 1.9, 4.7, 7.5, 10.3, and 13.1 inches from the bottom of the shaft. This placement will eliminate contact between the spikes of adjacent shafts since there will be a 1.03 inch horizontal clearance between the top of one spike and the bottom of the closest adjacent spike.

Opposite shafts will have their rows of spikes placed at the same distance horizontally from the bottom of the shaft. To avoid contact, the gears must originally be placed so that the spikes are at different angles. When one shaft has its spikes at angles of 0 , 90 , 180 , and 270 , the spikes of the shaft diametrically opposite should be at angles of 45 , 135 , 225 , and 315 . This will eliminate contact between spikes on opposite gears but will allow an overlap of 0.5 inches in the center of the chamber to ensure thorough mixing.

The total volume of the ingredients is 1.32 ft . With no shafts, the top of this volume would be at 12.907 inches from the bottom of the chamber. When the stirrers are introduced, the four shafts will increase the volume by 5.732 in and the eighty spikes will increase the volume by 31.623 in . Thus the total volume will be increased by 37.355 in and the top of the mixture will be raised 0.211 inches. (See Appendix B)

MOLDING

In the brick-making process, a mold is necessary to hold the sludge in its desired shape until the water is removed. The mold must be made of a material that permits the extraction of water from all faces of the object, but also one that is strong enough to not deflect under the weight of the brick. It must further be able to open so that the final product can be removed. In addition, the mold should be dynamic, enabling bricks of altered contact angle. This permits the stacking of the bricks in the parabolic shape necessary to maintain compression throughout the members. Finally, the mold must be able to be integrated into the remainder of the brick-making system in a logical and simple manner while still maintaining the environmental integrity of the system.

Factors Affecting Mold Material

In choosing the proper material for use as a mold, three factors are of great importance: strength, weight, and permeability.

Strength

When the sludge is dumped into the mold, the mold must be of sufficient strength to permit negligible deflection. As the load will be added and released many times, it must be designed to allow for fatigue effects as well static loads. On the moon, the brick will weigh 25 lbf, and any one surface should be able to withstand this load to allow for a reasonable factor of safety as the entire machine is worthless if the mold is not properly functioning.

Weight

While maintaining this strength, however, it is also desirable to maintain a low weight due to the cost of freight to the lunar surface. A lower mass will also make the mold more susceptible to any induced vibrations in the system, helping to settle the sludge.

This combination of properties of strength and weight is best suited to a composite material with a high strength-to-weight ratio such as a Kevlar-epoxy compound. Kevlar has a strength of 65,000 psi, and a density of only 0.05 lbm/in , giving it a strength to weight ratio of 1.3 x 10 inches, 4.06 times that of a high carbon steel. The density of the sludge is approximately

125 lbm/ft , and the volume of the brick is 1.2 ft . On the moon, this weighs 25 lbf. In the worst possible case, the bottom surface (which has the smallest surface area) supports the entire load. The minimum thickness of the material is thus found to be 192.3 microinches (See Appendix C). To allow in the design a safety factor against buckling, however, a thickness of 0.5 inches is recommended, assuming a negligible maximum deflection. The total volume of the mold is then computed to be about 576 cubic inches, which (for Kevlar) consists of 28.8 lbm. Complete calculations can be found in Appendix C.

Permeability

The mold must be more permeable than the brick material, because a lower permeability in the mold wall would result in a build-up of vapor pressure at the sludge-wall interface. This would cause a disproportionate amount of porosity at the surface of the brick, producing an unsound brick with a smaller effective size. To achieve the necessary equivalent permeability, the Kevlar must have a capillary density of at least 100 holes per square inch, with each hole having a diameter of 0.066 inches (see Appendix C). This so-called "equivalent permeability" is derived using a comparison of proportionality coefficients in Darcy's law of capillary flow between a normal porosity and an equivalent porosity. The equivalent porosity is derived using dimensional analysis on the properties of the fluid and the dimensions of the capillaries. Complete calculations can be found in appendix C.

Water Removal from Mold

For the lignin sulfonate bond to form, the water must be removed from the brick. This can be accomplished by allowing the water to diffuse out of the brick in either the liquid or gaseous state. Liquid diffusion through porous media is very slow; typically diffusion time for a process such as this one is on the order of hours. Therefore, a gaseous diffusion method is more desirable. To evaporate the water, two methods may be used:

1) Heat Addition

2) Pressure Removal

Heat Addition

Heat addition has the disadvantage of requiring rapid temperature changes. According to Lienhart, lunar soil has a specific heat of about 143.3 Btu/lbm F. Thus, raising the temperature from the process temperature of 77 F to water's atmospheric boiling temperature (212 F) would require ABOUT 130,000 Btu. Also, the thermal conductivity of the brick is very low, so it would take a great deal of time to heat and cool the brick repeatedly, which would render it impossible to meet the production rate specifications. Finally, if the water is to be boiled at even atmospheric pressure, the holding container must then be able to withstand a full 15 psia.

Pressure Removal

An alternate method, however, of converting the liquid water suspended in the brick into a vapor is through pressure removal. This process enables the water to boil out of the brick while the temperature of the brick remains essentially constant. Finally, if the pressure is to be dropped, a lower pressure can be used in the mold chamber and thus a lighter pressure vessel would be required.

Because of the weight and temperature advantage, the brick will be dried out through a vacuum drying process. This will be accomplished by pulling a hard vacuum on the entire mold chamber. Again, it is desirable to keep the drying process at as low a temperature as possible, as this dictates a lower pressure and thus determines the required load that the pressure chamber surrounding the mold must support. From the steam tables, we find that 2 psi is sufficient to hold water in the liquid state for up to approximately 120 degrees F. To allow for a reasonable safety factor, the molding process will be held at 77 F. To meet the production rate of one brick every 7.5 minutes, it is necessary to remove the water in less than 5 minutes. Throughout this analysis, the brick is approximated as a hollow cylinder of inside diameter 2 in, outside diameter 9 in, and height 18 in. While this is considerably larger than the brick, it allows use of polar equations, enabling the elimination of a non-linear term, and also allows for a worst possible case. The permeability of the brick is used because it is considered to be of greater fluid resistance than the mold. To determine the feasibility of the vacuum drying process, we turn to Luikov and Pascal. From Pascal we obtain the following differential equation (See Appendix C):

This equation can be solved numerically (See Appendix C) to yield a plot of pressure distribution at various times. The results are shown in Appendix C and are valid under the following assumptions:

* The boiling takes place faster than the diffusion.

* The permeability of the brick is approximately equal to that of a simulated earth sludge.

* The pressure at the boundary drops instantaneously to zero.

* The porosity of the brick is equal to unity.

The plots show that after 10 seconds, the maximum remaining pressure within the brick is less than .003 psi, which is approximately 1/700th of the initial pressure. From this, it is expected that the pressure will have reached its practical minimum in 30 seconds. This is acceptable as it is well within the necessary time frame to meet the production rate.

The analysis also shows that permeability has a very substantial effect on the rate of vapor pressure drop (or flow rate) in the brick. This can be seen by solving the differential equations using different initial conditions. The process, however can work as long as the coefficient Z (which is inversely proportional to the permeability), is less than 0.05.

Integration with the Remainder of the System

For the machine to work, the mold must be connected to the mixing chamber and the water reclamation system. It is connected directly to the mixing chamber in that the sludge must drop into the mold from above. This connection takes the form of a butterfly valve, as this will permit the chamber around the mold to be completely sealed, thereby enabling a near-perfect vacuum to be created for the dryout process. When this valve opens, the sludge will fall into the mold. The mold is oriented such that the lightening hole is vertical. This arrangement allows the brick to slide out of the mold when the bottom is removed. This removes the necessity of having two halves of a lengthwise mold that would have to be moved apart a full 18 inches to leave the brick completely exposed when it is removed. This feature permits the mold chamber to be thinner, thereby making the entire device more portable. Due to the sloped upper surface of the brick (See Drawing 4), no splash shield will be needed. A cover will be placed over the top of the hole to prevent any sludge from falling through the hole to the bottom of the surrounding chamber.

The connection to the water reclamation system, however, takes place merely in the fluid region. When the pressure is dropped, the gas is removed and the water turns into vapor and diffuses out of the brick and the mold. Finally, however, the brick must be dropped onto the conveyor system to remove the finished product. This can be accomplished by hinging the bottom surface of the mold and holding it in place with a latching device. When the latch is tripped, the door will swing down and away, enabling the brick to slide out under its own weight. This gate can be spring loaded so the gate will then close and self-latch in preparation for the next volume of sludge.

The Dynamic Mold

If the mold is to make bricks of varying contact angles, it must be dynamic in the sense that the mold must be able to slightly alter its shape. If the angle change is small enough, this can be accomplished by pivoting the walls towards the center. This cannot be dealt with here due to the lack of information as to the actual proposed structure, but it is an issue that should be addressed once the final shape of the dwelling is decided upon. If the angle change is significant, however, it may be necessary to use a carousel of molds that rotates after a given number of bricks are produced. This has the disadvantage, however, of making the device less portable due to size constraints.

WATER RECLAMATION

System and Process Description

System Description

The water reclamation process involves repressurizing and trapping the water vapor in a holding tank after it has been removed from the mold chamber through evacuation. Repressurization rather than refrigeration is chosen as the method for condensation of the water vapor because the vapor will be at such a low partial pressure after evacuation that simply cooling the vapor will not condense it. In addition, the lack of any mode of heat transfer on the lunar surface other than radiation to deep space makes it extremely difficult to design an efficient heat exchanging system for refrigeration.

As Drawing 5 shows, the water reclamation system consists of a two-stage vacuum pump system with an inter-stage condenser, a water pump, a water holding tank, a metering chamber, a nitrogen gas holding tank, and various pipes and valves connecting these components with the mixing and mold chambers. Initially, all valves are closed and all of the chambers are pressurized with nitrogen gas at an absolute pressure of 2.00 psia and an operational temperature of 77 degrees F. The water holding tank will initially contain the extra 0.392 cu. ft of water while the remaining 0.108 cu. ft is contained in the brick which is in the mold chamber.

Process Description

The repressurization process consists of the following steps. First, valve A, B, and C are opened and nitrogen gas in the mold chamber is evacuated via the vacuum pump system. As the pressure in the mold chamber drops below the vapor pressure of water (0.460 psia at 77 degrees F), the water contained in the brick vaporizes and diffuses from the brick. The first stage of the vacuum pump system pumps this nitrogen and water vapor mixture to the inter-stage condenser, which is just a section of piping with emitters attached on its outer surface to radiate heat into deep space. Here the water vapor condenses since the pressure in the condenser well exceeds the vapor pressure of water at the condenser temperature. The condensed water vapor flows through valve C due to gravity and is trapped in a section of piping called the condensate bleed-off pipe leading to the water pump. Meanwhile, the second stage of the vacuum pump pumps the nitrogen gas from the exit of the condenser to the nitrogen gas holding tank, pressurizing it. This continues until the pressure in the mold chamber drops to 0.001 psia. Then, valve A, B, and C are closed, valve D is opened, and the water pump pumps the trapped water up into the water holding tank. Finally, the water is recycled into the mixing chamber, and the nitrogen gas is recycled into the mold chamber. To recycle the water, valve D is closed, valve E is opened and water flows into the metering chamber via gravity. Since the metering chamber has a volume of exactly 0.108 cu. ft, by closing valve E and opening valve F, exactly 0.108 cu. ft of water flows into the mixing chamber. Recycling the nitrogen gas involves closing valve B, opening valve G, and bleeding the gas back into the mold chamber. Since the nitrogen gas holding tank is originally pressurized to the same pressure as the mold chamber, the mold chamber will be repressurized to exactly 2.00 psia.

Process Timing

Simulation of the water reclamation process reveals that by using a vacuum pump with a capacity of 70 cfs, the evacuation of the mold chamber from 2.00 psia to 0.001 psia can be achieved in 1 sec. However, since the water takes 30 secs. to completely evaporate from the brick, the pump system has to work the full 30 secs. to fully evacuate the mold chamber. In addition, using a standard water pump with a capacity of 50 GPH at a total head of 7.00 ft, the 0.108 cu. ft of water trapped in the interstage condenser can be pumped up to the water holding tank in 1 min. Dumping the water into the mixing chamber from the holding tank via gravity takes around 10 secs. Since the mixing takes place in the mixing chamber only, the nitrogen gas can be bleed back to the mold chamber during the time used for mixing which is 4 min. This process of bleeding will take an average mass flow rate of 3.61E-04 lbm per sec. In total, the water reclamation cycle takes 5 min. and 40 secs.

System Components

The Mold Chamber

The mold chamber is a cylindrical pressure vessel with hemispherical ends. It is oriented vertically with a total length of 2.50 ft and an outer diameter of 2.00 ft The mold chamber is made from formed A91100 aluminum sheets which are welded together. The walls of the mold chamber have a thickness of 0.100 in. except at the bottom where the thickness increases to 0.250 in. This increase in thickness is to accomidate the O-ring seal and locking mechanism of the brick unloading hatch at the bottom of the mold chamber. The thickness is increased gradually in order to avoid stress concentrations which may lead to failure due to bulging. A wall thickness of 0.100 in. is chosen since a wall thickness of less than 0.100 in. may lead to fatigue failure since the pressure in the chamber varies from 2.00 psia to 0.001 psia because there is no endurance limit for aluminum. As a result, The mold chamber is over-designed with a factor of safety of 21 for static failure. With this design, the mold chamber weights 75.4 lbf on Earth when empty.

The bottom hemispherical end of the mold chamber is a hatch which opens up when the chamber is evacuated to allow the brick to be removed from the mold. This hatch has an O-ring seal which provides an air tight seal when the mold chamber is pressurized. The hatch is hinged on the left side and is lowered by two two-arm linkages driven by an electric motor through direct drive. The motor is mounted on sheet aluminum brackets which are welded to the side of the mold chamber. The required horsepower of the electric motor to raise the hatch is 1/6 hp. The two two-arm linkages are mounted on the sides of the hatch perpendicular to where the motor is mounted. Each two arm linkage consists of two solid aluminum rods 1.00 ft in length and 0.500 in. in diameter. The locking mechanism for closing the hatch for repressurization consists of a ring of electromagnets which are placed around the outside of the hatch and the adjoining mold chamber. The magnets are activated when the hatch is closed in order to lock it and deactivated when the hatch is to be opened. The required current for the electromagnets is 3.00 Amps at 12 Volts when locking the hatch with an internal pressure of 2.00 psia. The entire hatch opening mechanism will weight 6.00 lbf on Earth.

Vacuum Pump System

The vacuum pump system consists of two stages with an inter-stage condenser which acts to condense the water for recycling. The first stage of the vacuum pump system consists of Oil-sealed rotary pump with a capacity of 70 cfs. This pump is to pump the nitrogen gas/water mixture from the mold chamber pressure (which varies from 2.00 psia to 0.001 psia) to a constant pressure of 0.450 psia at the entrance to the inter-stage condenser. This pressure at the entrance of the condenser is just below the vapor pressure of water in nitrogen gas at 77 degrees F. Since the temperature within the pump is above 77 degrees F due to the work put in by the pump, the water will not condense within the pump. The inter-stage condenser is just a section of piping with an inside diameter of 4.00 in. and a thickness of 0.250 in. On the outer surface of the condenser are emitters which serves to radiate heat out into deep space. On the bottom of the condenser is a funnel section of piping which leads to valve C. This is the bleed-off mechanism for the condensed water. As the water goes through the inter-stage condenser, the temperature will drop and the pressure will increase, thereby, causing the water to condense. This increase in pressure and decrease in temperature is due to back pressure from the second stage of the vacuum pump system and from heat transfer out of the condenser via radiation, respectively. The second stage of the vacuum pump system consists of a mechanical booster pump with a capacity of 70 cfs. The purpose of this pump is to pump the "dry" nitrogen gas from the exit of the condenser to the nitrogen gas holding tank. This will require the pump to pump from a constant pressure of 0.500 psia to the pressure in the nitrogen holding tank which varies from 2.00 psi to 6.24 psi. The required pump work varies as the chamber is evacuated. Maximum power requirement is 1/3 bhp for the two pumps. The vacuum pump system weights a total of 30 lbf on Earth.

Water Condensate Bleed-Off and Water Pump

The water condensate bleed-off is a piece of 4.00 in. ID steel piping that connects to the funnel section of the inter-stage condenser. The mechanism depends on gravity to force the condensate to collect at the bottom of the pipe section. From there the collected water is pumped to the water holding tank by a small water pump which activates when valve C closes and stops when the water level in the bleed-off piping reaches below 0.250 in. This will still leave 6.67E-03 cu. ft of water left at the bottom of the bleed-off piping. However, since the water reclamation process is continuous, this amount will always be left at the bottom of the piping resulting in near prefect reclamation of water during successive runs. The required power necessary to pump the water into the water holding tank is 1/4 bhp. The water pump weights 5.00 lbf.

Holding Tanks

The water reclamation process requires two holding tanks: one for water and another for nitrogen. Both tanks are thin wall spherical pressure vessels. The holding tank for water is 6.00 in. in diameter and is always pressurized to 2.00 psia. The holding tank for nitrogen is 1.00 ft in diameter, and its pressure varies from 2.00 psia to 6.24 psia. Both tanks, like the mold chamber, are constructed from 0.100 in. thick A91100 aluminum sheets which are formed and welded together. Like the mold chamber, both holding tanks are over-designed in order to prevent fatigue. The safety factor concerning static failure for this design is 12.4 and 13.5 for the water and nitrogen holding tanks, respectively. The water holding tank and the nitrogen holding tank weight 4.43 lbf and 17.7 lbf on Earth, respectively, when empty.

Connecting Pipes and Valves

The pipes connecting the components of the water reclamation system are standard 4.00 in. ID carbon steel pipes with a thickness of 0.500 in. Sections of piping include: 1.00 ft connecting the mold chamber to the first stage vacuum pump, 3.00 ft with two 90 degree elbows to connect the second stage pump to the nitrogen holding tank, and 3.00 ft for the bleed-off piping. All 4.00 in. pipes are connected with flange type mountings with O-ring seals. The connections are bolted together using 5-1/4 in. grade 5 bolts evenly spaced around the flange. This connection gives a minimum safety factor of 3. In addition, standard 1.00 in. ID carbon steel piping with a thickness of 0.315 in. is used to connect the nitrogen holding tank to the mold chamber and to connect the water pump to the water holding tank. The connections for these sections of piping are standard threaded couplings. The total weight of the pipes is 100 lbf on Earth.

The valves that are used for control of the various vapor and fluids routing lines are the commonly available solenoid actuated 'flip-flop' butterfly valves. These have been chosen because of their reliability, corrosion resistance, light weight, low power consumption and ability to handle both liquids and vapors.

System Control

Pump and Valve Control

All pump and valves operations are synchronized and controlled by a digital microprocessor controller which acts as a proportional controller. Since the system is composed strictly of first-order system components, proportional control will be optimal for this application. The control scheme is a simple one. Sensors, such as flow meters and pressure gages are located in the mold chamber and along the pipes. As the pressure in the mold chamber reaches 0.001 psia the pressure sensor will signal to the controller to close valves A, B, and C and to open valves D, and G. Similarily, the pump rates of the vacuum pump system is regulated from flow rate feedbacks from the flow meters along the pipes.

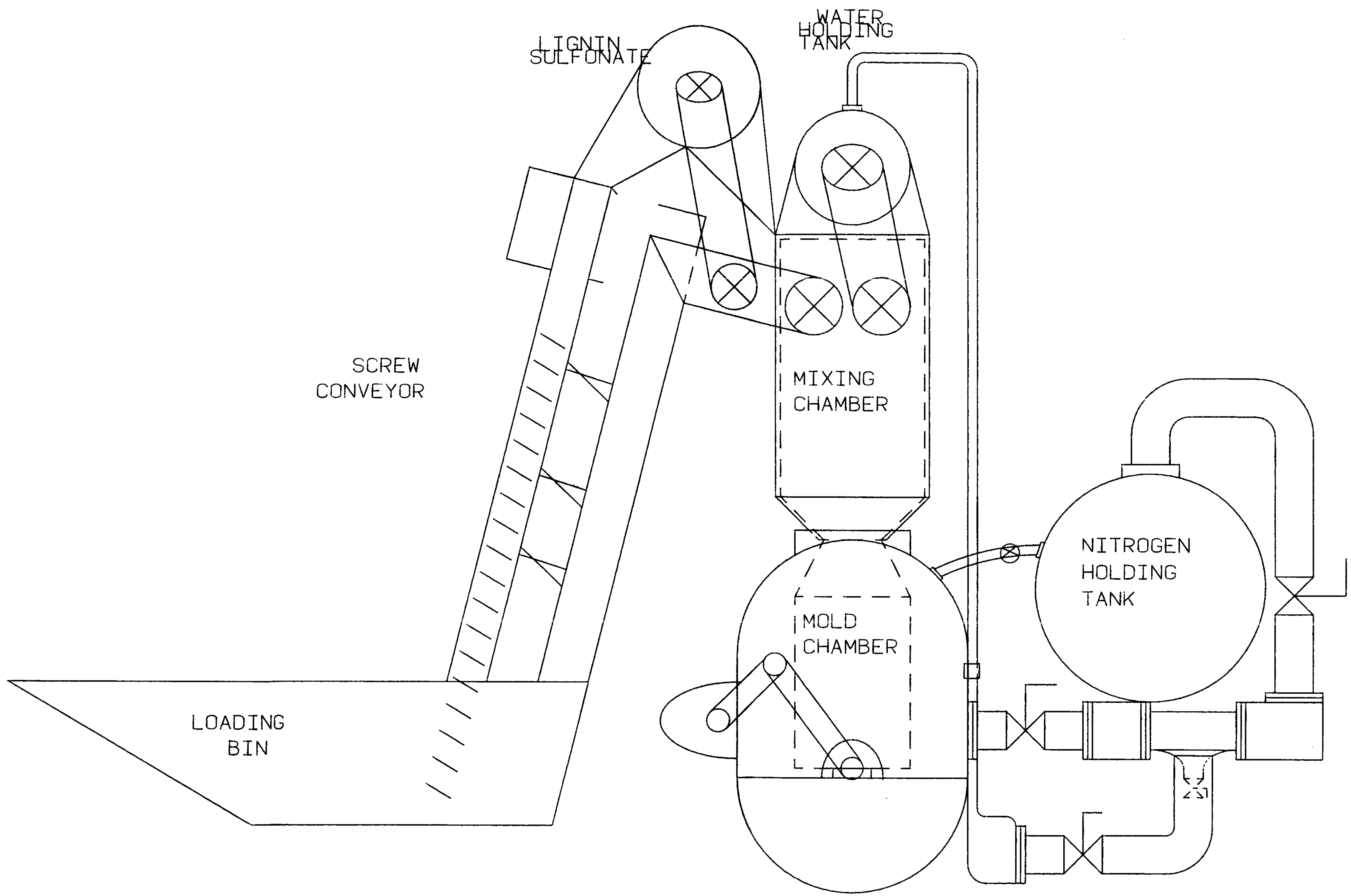
Temperature Control

In order for the vacuum pump system to work efficiently without failure, proper temperature control is essential. The proposed system for temperature control is to cover the outer surfaces of the pumps with emitters which will radiate continuously into deep space. By calculating the required heat transfer necessary, the correct emissivity of the emitters can be found. If the required heat transfer is too large, then another system composing of heat exchangers which will circulate a cooling fluid from the pumps to a larger radiator may be necessary. Due to lack of testing, however, this required heat transfer is presently unknown.

CONCLUSIONS AND RECOMMENDATIONS

This system is capable of producing the required 960 bricks required to build a structure on the moon. The bricks are made of the following: lunar fines, lignin sulfonate and water. The entire supply of bricks can be produced in 5 days. This will leave 8 days for placement of the bricks and construction of the lunar space building before the lunar day is over.

There are other aspects of this project which may require further analysis. Soil temperature must be maintained within a certain range of +/- 2.5 degrees C. Because the transport process of material to the mixing chamber involves timing, microprocessor control would be very helpful in regulating the opening and closing of valves. Further analysis of the transient flow in the pipes would serve to check for potential two-phase problems during water reclamation. Also, this system needs to be mounted upon some type of trailer for releasing the brick from the mold.



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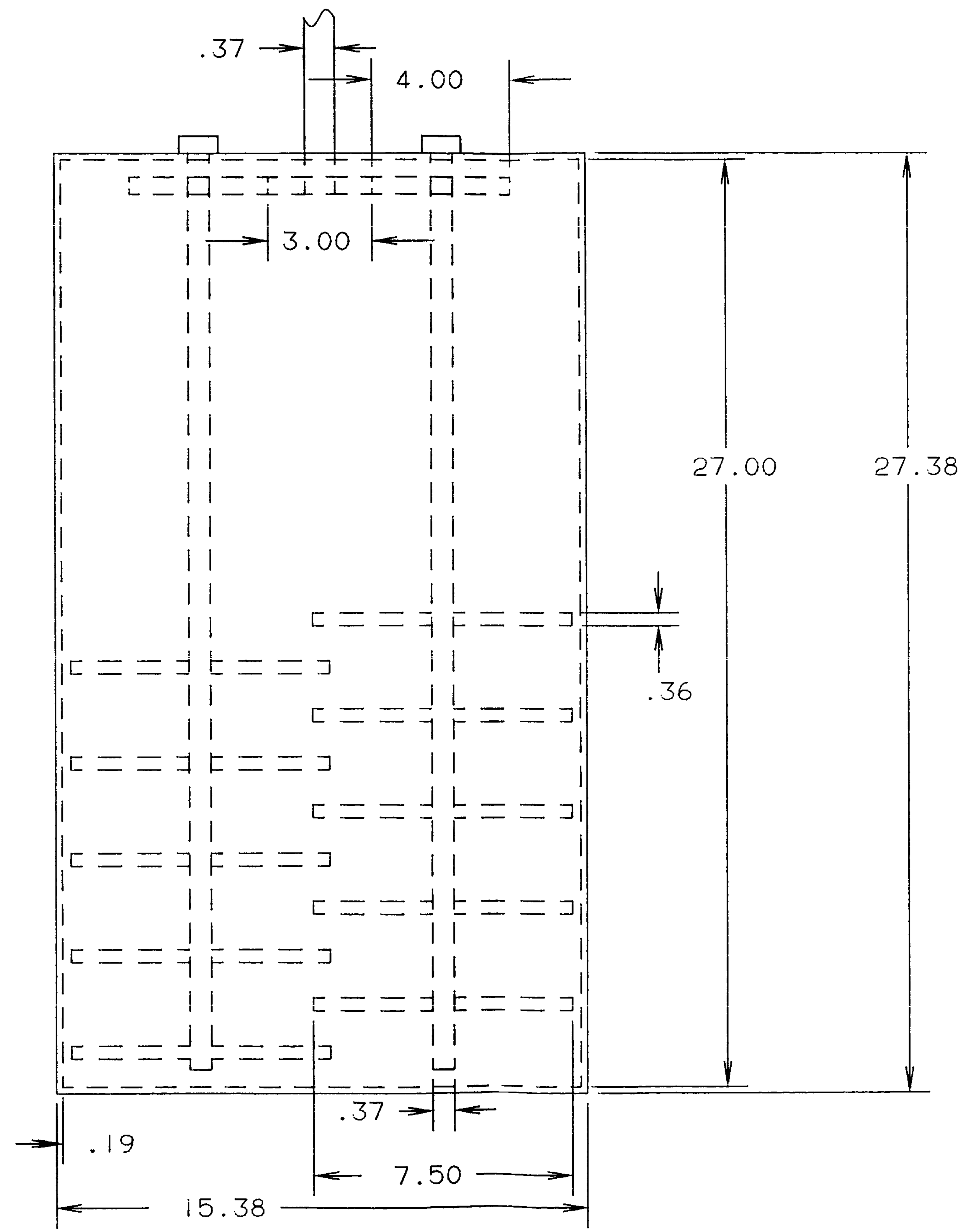

TWO OF FOUR

STIRRERS SHOWN

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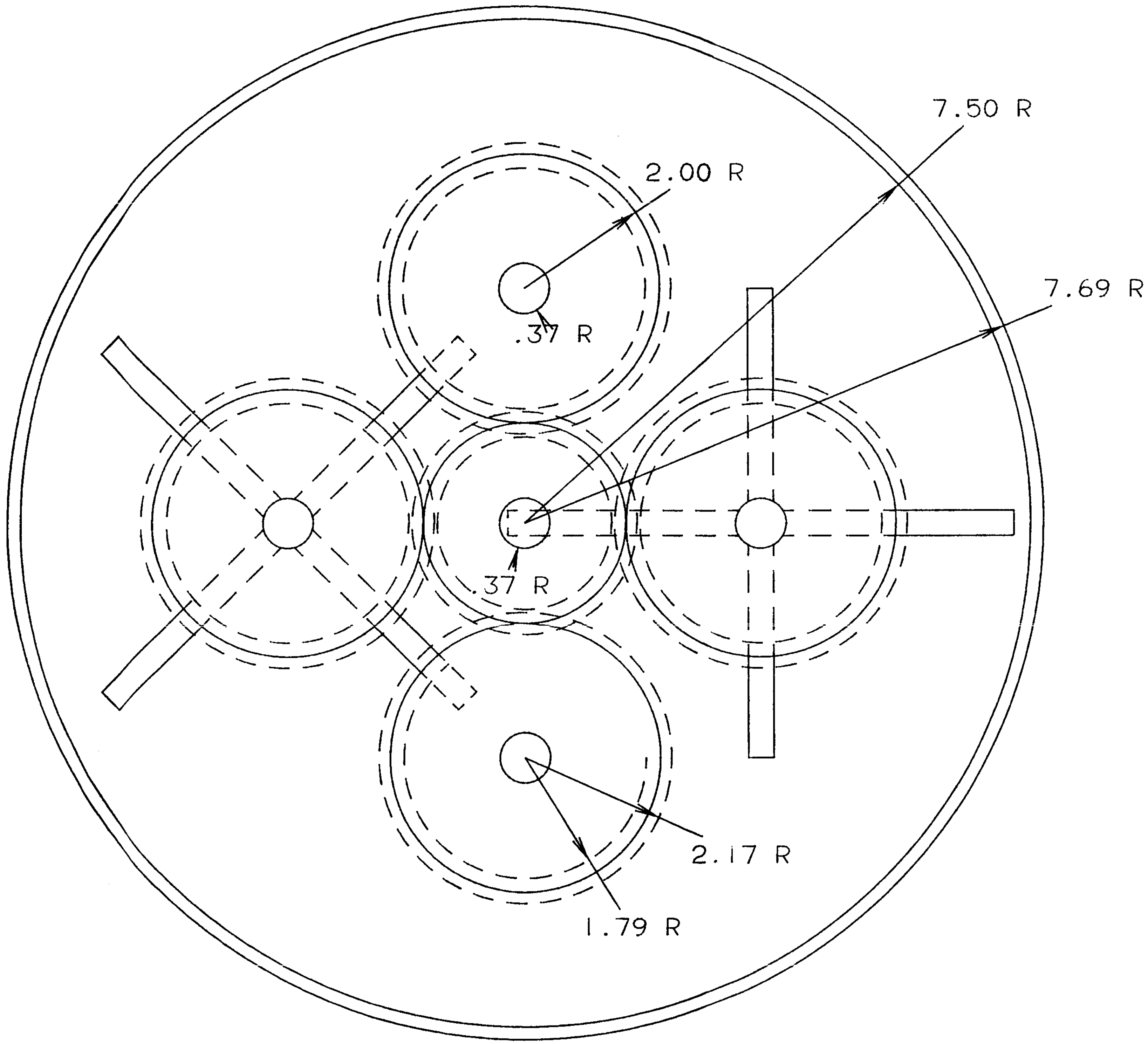

TWO OF FOUR

STIRRERS SHOWN

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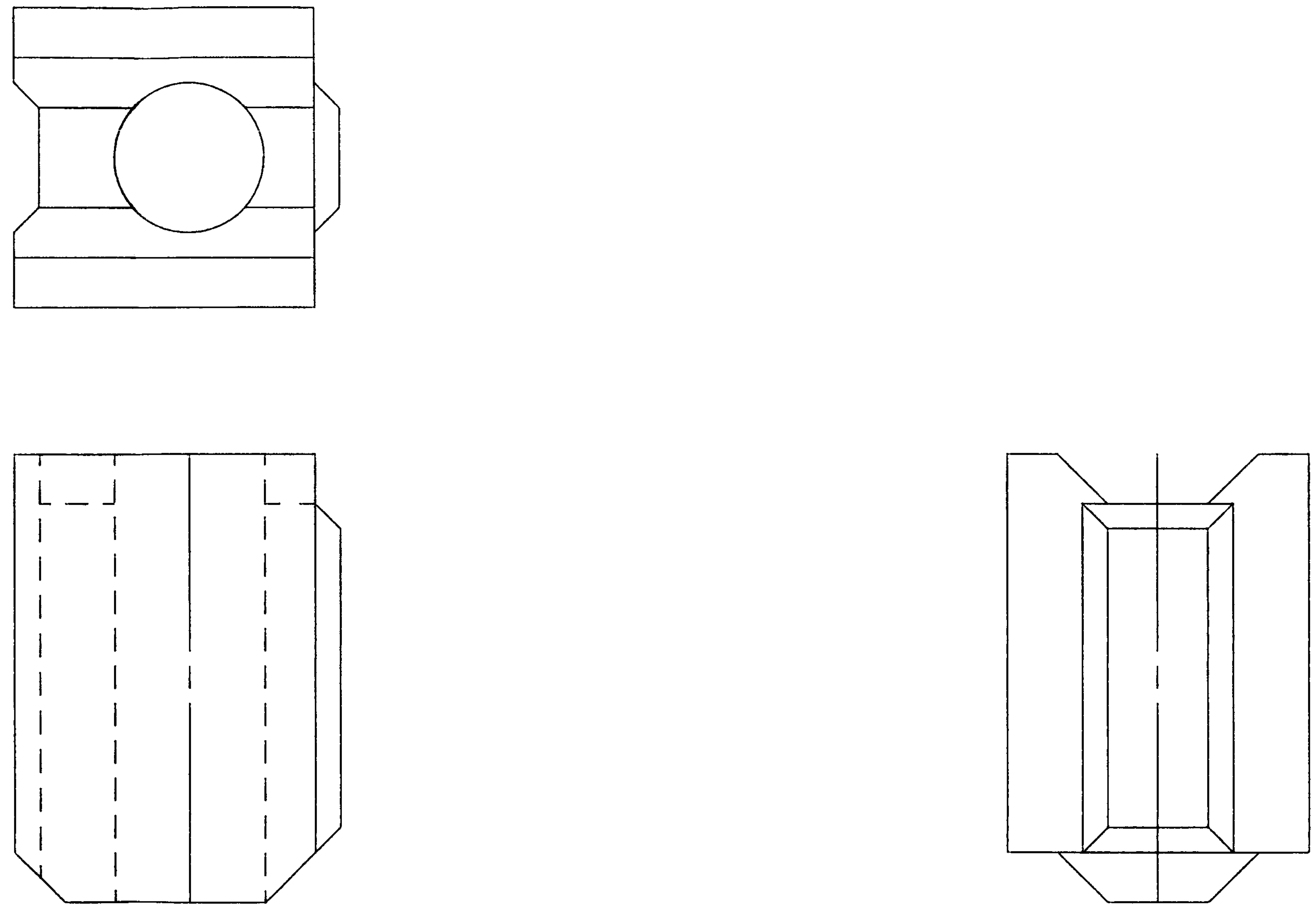

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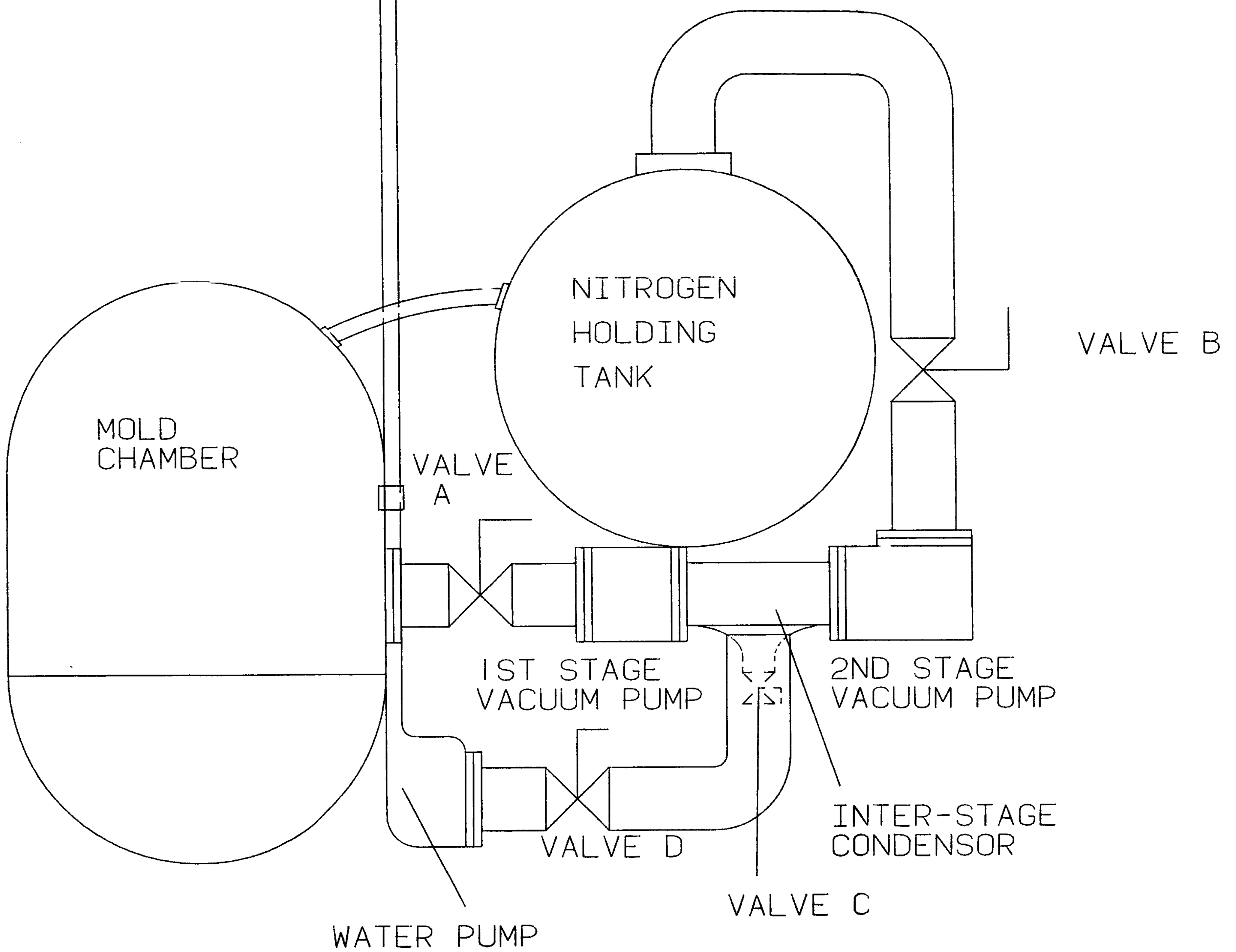

GEORGIA TECH COLLEGE OF ENGINEERING	
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APPENDIX A

Transportation

Calculations:

Bearing Reaction:

For pinion 3" and Gear 9"

Input: $H = 0.868$ HP.

$n = 86.5$ RPM = input speed

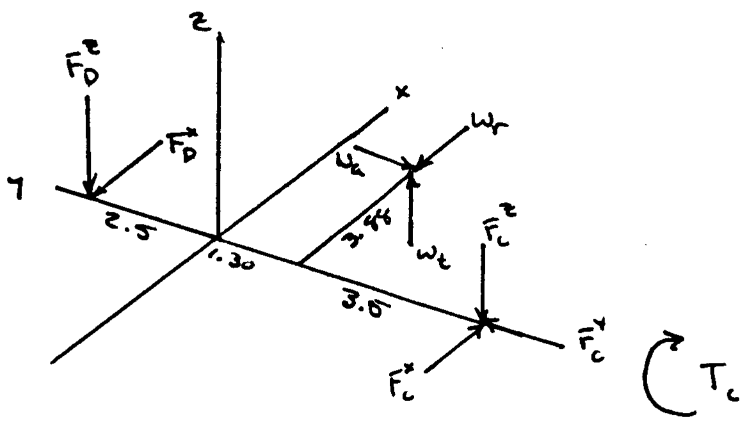
$r_p = 1.30$ in = average pitch radius

$$V = \frac{2\pi r_p n}{12} = \frac{2\pi(1.30)(86.5)}{12} = 59.0 \text{ fpm} = \text{pitch-line velocity}$$

$$W_t = \frac{33{,}000H}{V} = \frac{33{,}000(0.868)}{59.0} = 485.5 \text{ lb}$$

W_r = radial force = $W_t \tan\phi \cos\Gamma$ = $485.5 \tan 20 \cos 71.6 = 55.8$

W_a = axial force = $W_t \tan\phi \sin\Gamma$ = $485.5 \tan 20 \sin 71.6 = 167.5$



$R_G = 3.88\,i - (2.5 + 1.30)\,j$

$R_c = -(2.5 + 1.3 + 3.5) = -7.3\,j$

$\Sigma M_D = R_G \times W + R_c \times F_c + T = 0$

$3.88\,i + 3.80\,j \times (-55.8\,i - 167.5\,j + 485\,k) + (-7.30\,j) \times (F_c^x i + F_c^y j + F_c^z k) + T_c = 0$

$\boxed{F_c^z = -252 \text{ lb}}$

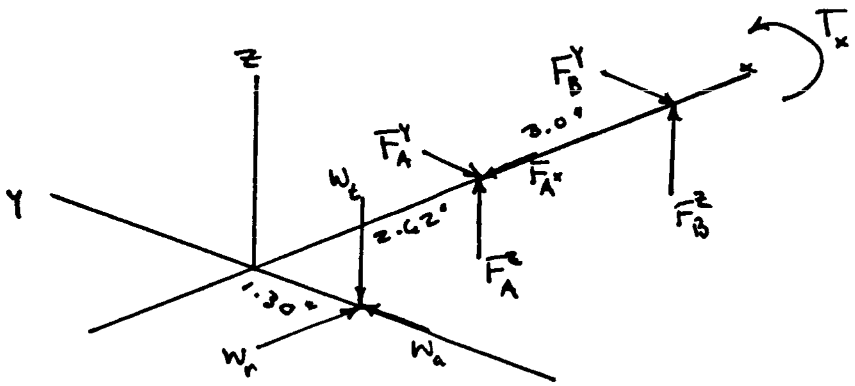
$\boxed{F_c^x = 118 \text{ lb}}$

$T_c = 1884$ in·lb $/12$ = $\boxed{157 \text{ ft·lb}}$ ✓ checks

$F_D + F_c + W = 0$

$$(F_D^x i + F_D^z k) + (118 i + F_C^y j - 252 k) + (-55.8 i - 167 j + 485 k)$$

$$\boxed{\begin{array}{l} F_D^x = -62.2 \text{ lb} \\ F_D^z = -232.8 \text{ lb} \\ F_C^y = 167.5 \text{ lb} \end{array}}$$



$$R_B = (-(3.0 + 2.62) i - 1.30 j)$$
$$R_A = -3.0 i$$
$$\Sigma M_B = R_B \times W + R_A \times F_A + T_x = 0$$
$$632 i - 2130 j + 72.5 k + 813.5 + 3.0 F_A^z j + 3.0 F_A^y k - T_x$$

$$\boxed{\begin{array}{l} F_A^z = 910 \text{ lb} \\ F_A^y = -80.3 \text{ lb} \end{array}}$$

$$F_B + F_A + W = 0$$
$$(-F_B^y j + F_B^z k) + (F_A^x i - 80.3 j - 910 k) + (55.8 i + 168 j - 486 k) = 0$$

$$\boxed{\begin{array}{l} F_A^x = -55.8 \text{ lb} \\ F_B^y = -87.7 \text{ lb} \\ F_B^z = 424 \text{ lb} \end{array}}$$

Calculations

Equivalent Dynamic Load:

$F_D^r = \sqrt{233^2 + 62.2^2} = 241 \text{ lb}$

$F_C^r = \sqrt{118^2 + 253^2} = 279 \text{ lb}$

$F_{th} = 167 \text{ lb}$

$S = 87 \text{ rpm}$

$L_{10} = 4000 \text{ hrs.}$

Shaft diameter = 50 mm

$F_T = 0.8$

$F_v = 1.0$

$a_{3l} = F_T F_v = 0.8$

Assume $K_B = K_A$

$$\frac{0.47 F_D^r}{K_a} \overset{?}{<} \left(\frac{0.47 F_C^r}{K_a} + F_{th} \right)$$

yes $$F_{aD} = \frac{0.47 F_C^r}{K_C} + F_{th} = 254 \text{ lb}$$

$$P_D = 0.4 F_D + K_D F_{aD} = 448 \text{ lb}$$

$$P_C = F_C^r = 279 \text{ lb}$$

Converting lb - N

$$C_{RD} = f_a P_D \left[\frac{L_{10} S}{a_{3l}(1.5 \times 10^6)} \right] = 1163 \text{ N}$$

$$C_{RC} = 927 \text{ N}$$

From tables, we choose bearings with (I.D. 1.97) O.D. 3.14 in and width 0.787".

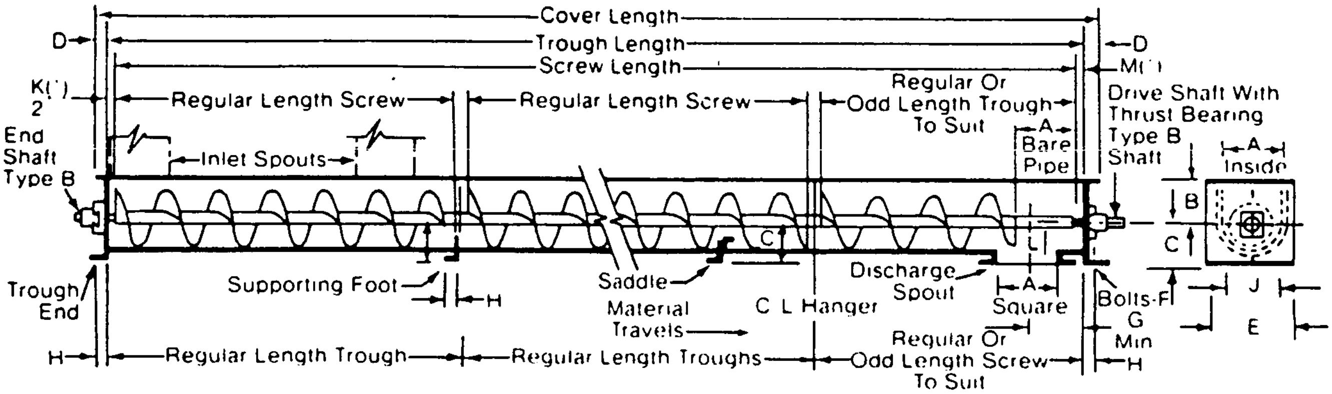


Figure B

Table 1 Layout Using No. 216, 220, 226, 270, 316, or 326 Hangers

Screw Dia	Shaft and Coupling Dia	Conveyor Screw: Regular Length: Screw Length	Conveyor Screw: Regular Length: Hanger Centers	Conveyor Screw: Half Length: Screw Length	Conveyor Screw: Half Length: Hanger Centers	Conveyor Trough: Reg Length	Conveyor Trough: Half Length	A	B	C	D	E	F (²)	G	H	J (²)	K	L	M(¹) Steel Plate Trough End: Plain Drive Shaft	M(¹) Steel Plate Trough End: Drive Shaft With Bronze Thrust Bearing	M(¹) Drive Shaft Trough End: Ball Bearing	M(¹) Drive Shaft Trough End: Roller Bearing
Inches		Feet and Inches						Inches														
4	1	9-10½	10-0	4-10½	5-0	10-0	5-0	5	3⅝	4⅝	1½	3⅛	⅜	6	1	2⅞	1½	3¾	¾	—	—	—
6	1½	9-10	10-0	4-10	5-0	10-0	5-0	7	4½	5⅝	1½	4⅛	⅜	7½	1	4 1/16	2	5	1	1	1	1
9	1½	9-10	10-0	4-10	5-0	10-0	5-0	10	6⅛	7⅞	1⅝	6⅛	½	10	1½	4 11/16	2	7⅛	1	1	1	1
	2	9-10	10-0	4-10	5-0	10-0	5-0	10	6⅛	7⅞	1⅝	6⅛	½	10	1½	4 11/16	2	7⅛	1	1	1	1
10	1½	9-10	10-0	4-10	5-0	10-0	5-0	11	6⅜	8⅛	1¾	7⅜	½	11	1¾	4¾	2	7⅞	1	1	1	1
	2	9-10	10-0	4-10	5-0	10-0	5-0	11	6⅜	8⅛	1¾	7⅜	½	11	1¾	4¾	2	7⅞	1	1	1	1
12	2	11-10	12-0	5-10	6-0	12-0	6-0	13	7¾	9⅝	2	8⅝	⅝	12½	1⅞	6⅛	2	8⅞	1	1	1	1
	2 7/16	11-9	12-0	5-9	6-0	12-0	6-0	13	7¾	9⅝	2	8⅝	⅝	12½	1⅞	6⅛	3	8⅞	1½	1½	1½	1½
	3	11-9	12-0	5-9	6-0	12-0	6-0	13	7¾	9⅝	2	8⅝	⅝	12½	1⅞	6⅛	3	8⅞	1½	1½	1½	1½
14	2 7/16	11-9	12-0	5-9	6-0	12-0	6-0	15	9¼	10⅝	2	9⅝	⅝	13½	1⅞	6¾	3	10⅛	1½	1½	1½	1½
	3	11-9	12-0	5-9	6-0	12-0	6-0	15	9¼	10⅝	2	9⅝	⅝	13½	1⅞	6¾	3	10⅛	1½	1½	1½	1½
16	3	11-9	12-0	5-9	6-0	12-0	6-0	17	10⅝	12	2½	10⅝	⅝	14½	2	7 7/16	3	11⅛	1½	1½	1½	1½
18	3	11-9	12-0	5-9	6-0	12-0	6-0	19	12⅛	13⅜	2½	12⅛	⅝	16½	2	8	3	12⅜	1½	1½	1½	1½
	3 7/16	11-8	12-0	5-8	6-0	12-0	6-0	19	12⅛	13⅜	2½	12⅛	⅝	16½	2	8	4	12⅜	2	2	2	2
20	3	11-9	12-0	5-9	6-0	12-0	6-0	21	13½	15	2½	13⅛	¾	17½	2¼	9⅜	3	13⅜	1½	1½	1½	1½
	3 7/16	11-8	12-0	5-8	6-0	12-0	6-0	21	13½	15	2½	13⅛	¾	17½	2¼	9⅜	4	13⅜	2	2	2	2
24	3 7/16	11-8	12-0	5-8	6-0	12-0	6-0	25	16½	18⅛	2½	15⅛	¾	20	2½	10	4	15⅜	2	2	2	2

(¹) Varies slightly when drive shaft assemblies with thrust provisions are provided.
(²) Dimensions same for trough ends, supporting feet and saddles.

Table 3 Material Classification Code Chart

Major Class	Material Characteristics Included		Code Designation
Density	Bulk Density, Loose		Actual lbs/ft^3
Size	Very Fine	No. 200 Sieve (.0029") And Under	A_{200}
		No. 100 Sieve (.0059") And Under	A_{100}
		No. 40 Sieve (.016") And Under	A_{40}
	Fine	No. 6 Sieve (.132") And Under	B_0
	Granular	½" And Under	$C_{1/2}$
	Granular	3" And Under	D_3
	(1)Lumpy	Over 3" To Be Special X=Actual Maximum Size	D_x
	Irregular	Stringy, Fibrous, Cylindrical, Slabs, etc.	F
Flowability	Very Free Flowing – Flow Function 10		1
	Free Flowing – Flow Function >4 But < 10		2
	Average Flowability – Flow Function >2 But < 4		3
	Sluggish – Flow Function < 2		4
Abrasiveness	Mildly Abrasive – Index 1-17		5
	Moderately Abrasive – Index 18-67		6
	Extremely Abrasive – Index 68-416		7
Miscellaneous Properties Or Hazards	Builds Up and Hardens		F
	Generates Static Electricity		G
	Decomposes – Deteriorates in Storage		H
	Flammability		J
	Becomes Plastic or Tends to Soften		K
	Very Dusty		L
	Aerates and Becomes Fluid		M
	Explosiveness		N
	Stickiness-Adhesion		O
	Contaminable, Affecting Use		P
	Degradable, Affecting Use		Q
	Gives Off Harmful or Toxic Gas or Fumes		R
	Highly Corrosive		S
	Mildly Corrosive		T
	Hygroscopic		U
	Interlocks, Mats or Agglomerates		V
	Oils Present		W
	Packs Under Pressure		X
	Very Light and Fluffy – May Be Windswept		Y
	Elevated Temperature		Z

(1) Refer to page B-37 for lump size limitations

Table 4 Material Characteristics

Material	Weight lbs/ft³	Material Code	Component Series	Mat'l. Factor Fm
Adipic Acid	45	$45A_{100}35$	2B	.5
Alfalfa Meal	14-22	$18B_{6}45WY$	2D	.6
Alfalfa Pellets	41-43	$42C_{1/2}25$	2D	.5
Alfalfa Seed	10-15	$13B_{6}15N$	1A-1B-1C	.4
Almonds, Broken	27-30	$29C_{1/2}35Q$	2D	.9
Almonds, Whole Shelled	28-30	$29C_{1/2}35Q$	2D	.9
Alum, Fine	45-50	$48B_{6}35U$	1A-1B-1C	.6
Alum, Lumpy	50-60	$55B_{6}25$	2A-2B	1.4
Alumina	55-65	$58B_{6}27MY$	3D	1.8
Alumina Fines	35	$35A_{100}27MY$	3D	1.6
Alumina Sized or Briquette	65	$65D_{3}37$	3D	2.0
Aluminate Gel (Aluminate Hydroxide)	45	$45B_{6}35$	2D	1.7
Aluminum Chips, Dry	7-15	11E45V	2D	1.2
Aluminum Chips, Oily	7-15	11E45V	2D	.8
Aluminum Hydrate	13-20	$17C_{1/2}35$	1A-1B-1C	1.4
Aluminum Ore (See Bauxite)	—	—	—	—
Aluminum Oxide	60-120	$90A_{100}17M$	3D	1.8
Aluminum Silicate (Andalusite)	49	$49C_{1/2}35S$	3A-3B	.8
Aluminum Sulfate	45-58	$52C_{1/2}25$	1A-1B-1C	1.0
Ammonium Chloride, Crystalline	45-52	$49A_{100}45FRS$	3A-3B	.7
Ammonium Nitrate	45-62	$54A_{40}35NTU$	3D	1.3
Ammonium Sulfate	45-58	$52C_{1/2}35FOTU$	1A-1B-1C	1.0
Antimony Powder	—	$A_{100}35$	2D	1.6
Apple Pomace, Dry	15	$15C_{1/2}45Y$	2D	1.0
Arsenate of Lead (See Lead Arsenate)	—	—	—	—
Arsentic Oxide (Arsenolite)(1)	100-120	$110A_{100}35R$	—	—
Arsentic Pulverized	30	$30A_{100}25R$	2D	.8
Asbestos-Rock (Ore)	81	$81D_{3}37R$	3D	1.2
Asbestos-Shredded	20-40	30E46XY	2D	1.0
Ash, Black Ground	105	$105B_{6}35$	1A-1B-1C	2.0
Ashes, Coal, Dry — ½"	35-45	$40C_{1/2}46TY$	3D	3.0
Ashes, Coal, Dry — 3"	35-40	$38D_{3}46T$	3D	2.5
Ashes, Coal, Wet — ½"	45-50	$48C_{1/2}46T$	3D	3.0
Ashes, Coal, Wet — 3"	45-50	$48D_{3}46T$	3D	4.0
Ashes, Fly (See Fly Ash)	—	—	—	—
Ashphalt, Crushed — ½"	45	$45C_{1/2}45$	1A-1B-1C	2.0
Bagasse	7-10	9E45RVXY	2A-2B-2C	1.5
Bakelite, Fine	30-45	$38B_{6}25$	1A-1B-1C	1.4
Baking Powder	40-55	$48A_{100}35$	1B	.6
Baking Soda (Sodium Bicarbonate)	40-55	$48A_{100}25$	1B	.6
Barite (Barium Sulfate) + ½" — 3"	120-180	$150D_{3}36$	3D	2.6
Barite, Powder	120-180	$150A_{100}35X$	2D	2.0
Barium Carbonate	72	$72A_{100}45R$	2D	1.6
Bark, Wood, Refuse	10-20	15E45TVY	3D	2.0
Barley, Fine, Ground	24-38	$31B_{6}35$	1A-1B-1C	.4
Barley, Malted	31	$31C_{1/2}35$	1A-1B-1C	.4
Barley, Meal	28	$28C_{1/2}35$	1A-1B-1C	.4
Barley, Whole	36-48	$42B_{6}25N$	1A-1B-1C	.5
Basalt	80-105	$93B_{6}27$	3D	1.8
Bauxite, Dry, Ground	68	$68B_{6}25$	2D	1.8
Bauxite, Crushed — 3"	75-85	$80D_{3}36$	3D	2.5
Beans, Castor, Meal	35-40	$38B_{6}35W$	1A-1B-1C	.8
Beans, Castor, Whole Shelled	36	$36C_{1/2}15W$	1A-1B-1C	.5
Beans, Navy, Dry	48	$48C_{1/2}15$	1A-1B-1C	.5
Beans, Navy, Steeped	60	$60C_{1/2}25$	1A-1B-1C	.8

(1)Consult FMC

Table 4 (cont'd) Material Characteristics

Material	Weight lbs/ft³	Material Code	Component Series	Mat'l. Factor Fm
Bentonite, Crude	34-40	37D$_3$45X	2D	1.2
Bentonite, – 100 Mesh	50-60	55A$_{100}$25MXY	2D	.7
Benzene Hexachloride	56	56A$_{100}$45R	1A-1B-1C	.6
Bicarbonate of Soda (Baking Soda)	–	–	1B	.6
Blood, Dried	35-45	40D$_3$45U	2D	2.0
Blood, Ground, Dried	30	30A$_{100}$35U	1A-1B	1.0
Bone Ash (Tricalcium Phosphate)	40-50	45A$_{100}$45	1A-1B	1.6
Boneblack	20-25	23A$_{100}$25Y	1A-1B	1.5
Bonechar	27-40	34B$_6$35	1A-1B	1.6
Bonemeal	50-60	55B$_6$35	2D	1.7
Bones, Whole(¹)	35-50	43E45V	2D	3.0
Bones, Crushed	35-50	43D$_3$45	2D	2.0
Bones, Ground	50	50B$_6$35	2D	1.7
Borate of Lime	60	60A$_{100}$35	1A-1B-1C	.6
Borax, Fine	45-55	50B$_6$25T	3D	.7
Borax Screening – ½"	55-60	58C$_{1/2}$35	2D	1.5
Borax, 1½"-2" Lump	55-60	58D$_3$35	2D	1.8
Borax, 2"-3" Lump	60-70	65D$_3$35	2D	2.0
Boric Acid, Fine	55	55B$_6$25T	3D	.8
Boron	75	75A$_{100}$37	2D	1.0
Bran, Rice-Rye-Wheat	16-20	18B$_6$35NY	1A-1B-1C	.5
Braunite (Manganese Oxide)	120	120A$_{100}$36	2D	2.0
Bread Crumbs	20-25	23B$_6$35PQ	1A-1B-1C	.6
Brewer's Grain, spent, dry	14-30	22C$_{1/2}$45	1A-1B-1C	.5
Brewer's Grain, spent, wet	55-60	58C$_{1/2}$45T	2A-2B	.8
Brick, Ground – ⅛"	100-120	110B$_6$37	3D	2.2
Bronze Chips	30-50	40B$_6$45	2D	2.0
Buckwheat	37-42	40B$_6$25N	1A-1B-1C	.4
Calcine, Flour	75-85	80A$_{100}$35	1A-1B-1C	.7
Calcium Carbide	70-90	80D$_3$25N	2D	2.0
Calcium Carbonate (See Limestone)	–	–	–	–
Calcium Fluoride (See Fluorspar)	–	–	–	–
Calcium Hydrate (See Lime, Hydrated)	–	–	–	–
Calcium Hydroxide (See Lime, Hydrated)	–	–	–	–
Calcium Lactate	26-29	28D$_3$45QTR	2A-2B	.6
Calcium Oxide (See Lime, unslaked)	–	–	–	–
Calcium Phosphate	40-50	45A$_{100}$45	1A-1B-1C	1.6
Calcium Sulfate (See Gypsum)	–	–	–	–
Carbon, Activated, Dry, Fine(¹)	–	–	–	–
Carbon Black, Pelleted(¹)	–	–	–	–
Carbon Black, Powder(¹)	–	–	–	–
Carborundum	100	100D$_3$27	3D	3.0
Casein	36	36B$_6$35	2D	1.6
Cashew Nuts	32-37	35C$_{1/2}$45	2D	.7
Cast Iron, Chips	130-200	165C$_{1/2}$45	2D	4.0
Caustic Soda	88	88B$_6$35RSU	3D	1.8
Caustic Soda, Flakes	47	47C$_{1/2}$45RSUX	3A-3B	1.5
Celite (See Diatomaceous Earth)	–	–	–	–
Cement, Clinker	75-95	85D$_3$36	3D	1.8
Cement, Mortar	133	133B$_6$35Q	3D	3.0
Cement, Portland	94	94A$_{100}$26M	2D	1.4
Cement, Aerated (Portland)	60-75	68A$_{100}$16M	2D	1.4

(¹)Consult FMC

Table 4 (cont'd) Material Characteristics

Material	Weight lbs/ft³	Material Code	Component Series	Mat'l. Factor Fm
Cerrusite (See Lead Carbonate)	—	—	—	—
Chalk, Crushed	75-95	85D$_3$25	2D	1.9
Chalk, Pulverized	67-75	71A$_{100}$25MXY	2D	1.4
Charcoal, Ground	18-28	23A$_{100}$45	2D	1.2
Charcoal, Lumps	18-28	23D$_3$45Q	2D	1.4
Chocolate, Cake Pressed	40-45	43D$_3$25	2B	1.5
Chrome Ore	125-140	133D$_3$36	3D	2.5
Cinders, Blast Furnace	57	57D$_3$36T	3D	1.9
Cinders, Coal	40	40D$_3$36T	3D	1.8
Clay (See Bentonite, Diatomaceous Earth, Fuller's Earth, Kaolin & Marl)	—	—	—	—
Clay, Ceramic, Dry, Fines	60-80	70A$_{100}$35P	1A-1B-1C	1.5
Clay, Calcined	80-100	90B$_6$36	3D	2.4
Clay, Brick, Dry, Fines	100-120	110C$_{1/2}$36	3D	2.0
Clay, Dry, Lumpy	60-75	68D$_3$35	2D	1.8
Clinker, Cement (See Cement Clinker)	—	—	—	—
Clover Seed	45-48	47B$_6$25N	1A-1B-1C	.4
Coal, Anthracite (River & Culm)	55-61	60B$_6$35TY	2A-2B	1.0
Coal, Anthracite, Sized — ½"	49-61	55C$_{1/2}$25	2A-2B	1.0
Coal, Bituminous, Mined	40-60	50D$_3$35LNXY	1A-1B	.9
Coal, Bituminous, Mined, Sized	45-50	48D$_3$35QV	1A-1B	1.0
Coal, Bituminous, Mined, Slack	43-50	47C$_{1/2}$45T	2A-2B	.9
Coal, Lignite	37-45	41D$_3$35T	2D	1.0
Cocoa Beans	30-45	38C$_{1/2}$25Q	1A-1B	.5
Cocoa, Nibs	35	35C$_{1/2}$25	2D	.5
Cocoa, Powdered	30-35	33A$_{100}$45XY	1B	.9
Cocoanut, Shredded	20-22	21E45	2B	1.5
Coffee, Chaff	20	20B$_6$25MY	1A-1B	1.0
Coffee, Green Bean	25-32	29C$_{1/2}$25PQ	1A-1B	.5
Coffee, Ground, Dry	25	25A$_{40}$35P	1A-1B	.6
Coffee, Ground, Wet	35-45	40A$_{40}$45X	1A-1B	.6
Coffee, Roasted Bean	20-30	25C$_{1/2}$25PQ	1B	.4
Coffee, Soluble	19	19A$_{40}$35PUY	1B	.4
Coke, Breeze	25-35	30C$_{1/2}$37	3D	1.2
Coke, Loose	23-35	30D$_7$37	3D	1.2
Coke, Petrol, Calcined	35-45	40D$_7$37	3D	1.3
Compost	30-50	40D$_7$45TV	3A-3B	1.0
Concrete, Pre-Mix Dry	85-120	103C$_{1/2}$36U	3D	3.0
Copper Ore	120-150	135D$_x$36	3D	4.0
Copper Ore, Crushed	100-150	125D$_3$36	3D	4.0
Copper Sulphate, (Bluestone)	75-95	85C$_{1/2}$35S	2A-2B-2C	1.0
Copperas (See Ferrous Sulphate)	—	—	—	—
Copra, Cake Ground	40-45	43B$_6$45HW	1A-1B-1C	.7
Copra, Cake, Lumpy	25-30	28D$_3$35HW	2A-2B-2C	.8
Copra, Lumpy	22	22E35HW	2A-2B-2C	1.0
Copra, Meal	40-45	42B$_6$35HW	2D	.7
Cork, Fine Ground	5-15	10B$_6$35JNY	1A-1B-1C	.5
Cork, Granulated	12-15	14C$_{1/2}$35JY	1A-1B-1C	.5
Corn, Cracked	40-50	45B$_6$25P	1A-1B-1C	.7
Corn Cobs, Ground	17	17C$_{1/2}$25Y	1A-1B-1C	.6
Corn Cobs, Whole(¹)	12-15	14E35	2A-2B	—
Corn Ear(¹)	56	56E35	2A-2B	—
Corn Germ	21	21B$_6$35PY	1A-1B-1C	.4
Corn Grits	40-45	43B$_6$35P	1A-1B-1C	.5
Cornmeal	32-40	36B$_6$35P	1A-1B	.5
Corn Oil, Cake	25	25D$_7$45HW	1A-1B	.6

(¹)Consult FMC

Table 4 (cont'd) Material Characteristics

Material	Weight lbs/ft³	Material Code	Component Series	Mat'l. Factor Fm
Corn Seed	45	$45C_{1/2}25PQ$	1A-1B-1C	.4
Corn Shelled	45	$45C_{1/2}25$	1A-1B-1C	.4
Corn Sugar	30-35	$33B_{6}35PU$	1B	1.0
Cottonseed, Cake, Crushed	40-45	$43C_{1/2}45HW$	1A-1B	1.0
Cottonseed, Cake, Lumpy	40-45	$43D_{7}45HW$	2A-2B	1.0
Cottonseed, Dry, Delinted	22-40	$31C_{1/2}25X$	1A-1B	.6
Cottonseed, Dry, Not Delinted	18-25	$22C_{1/2}45XY$	1A-1B	.9
Cottonseed, Flakes	20-25	$23C_{1/2}35HWY$	1A-1B	.8
Cottonseed, Hulls	12	$12B_{6}35Y$	1A-1B	.9
Cottonseed, Meal, Expeller	25-30	$28B_{6}45HW$	3A-3B	.5
Cottonseed, Meal, Extracted	35-40	$37B_{6}45HW$	1A-1B	.5
Cottonseed, Meats, Dry	40	$40B_{6}35HW$	1A-1B	.6
Cottonseed, Meats, Rolled	35-40	$38C_{1/2}45HW$	1A-1B	.6
Cracklings, Crushed	40-50	$45D_{3}45HW$	2A-2B-2C	1.3
Cryolite, Dust	75-90	$83A_{100}36L$	2D	2.0
Cryolite, Lumpy	90-110	$100D_{16}36$	2D	2.1
Cullet, Fine	80-120	$100C_{1/2}37$	3D	2.0
Cullet, Lump	80-120	$100D_{16}37$	3D	2.5
Culm (See Coal, Anthracite)	—	—	—	—
Cupric Sulphate (Copper Sulfate)	—	—	—	—
Detergent (See Soap Detergent)	—	—	—	—
Diatomaceous Earth	11-17	$14A_{40}36Y$	3D	1.6
Dicalcium Phosphate	40-50	$45A_{40}35$	1A-1B-1C	1.6
Disodium Phosphate	25-31	$28A_{40}35$	3D	.5
Distiller's Grain, Spent Dry	30	$30B_{6}35$	2D	.5
Distiller's Grain, Spent Wet	40-60	$50C_{1/2}45V$	3A-3B	.8
Dolomite, Crushed	80-100	$90C_{1/2}36$	2D	2.0
Dolomite, Lumpy	90-100	$95D_{X}36$	2D	2.0
Earth, Loam, Dry, Loose	76	$76C_{1/2}36$	2D	1.2
Ebonite, Crushed	63-70	$67C_{1/2}35$	1A-1B-1C	.8
Egg Powder	16	$16A_{40}35MPY$	1B	1.0
Epsom Salts (Magnesium Sulfate)	40-50	$45A_{40}35U$	1A-1B-1C	.8
Feldspar, Ground	65-80	$73A_{100}37$	2D	2.0
Feldspar, Lumps	90-100	$95D_{7}37$	2D	2.0
Feldspar, Powder	100	$100A_{200}36$	2D	2.0
Feldspar, Screenings	75-80	$78C_{1/2}37$	2D	2.0
Ferrous Sulfide – ½"	120-135	$128C_{1/2}26$	1A-1B-1C	2.0
Ferrous Sulfide – 100M	105-120	$113A_{100}36$	1A-1B-1C	2.0
Ferrous Sulphate	50-75	$63C_{1/2}35U$	2D	1.0
Fish Meal	35-40	$38C_{1/2}45HP$	1A-1B-1C	1.0
Fish Scrap	40-50	$45D_{7}45H$	2A-2B-2C	1.5
Flaxseed	43-45	$44B_{6}35X$	1A-1B-1C	.4
Flaxseed Cake (Linseed Cake)	48-50	$49D_{7}45W$	2A-2B	.7
Flaxseed Meal (Linseed Meal)	25-45	$35B_{6}45W$	1A-1B	.4
Four Wheat	33-40	$37A_{40}45LP$	1B	.6
Flue Dust, Basic Oxygen Furnace	45-60	$53A_{40}36LM$	3D	3.5
Flue Dust, Blast Furnace	110-125	$118A_{40}36$	3D	3.5
Flue Dust, Boiler H. Dry	30-45	$38A_{40}36LM$	3D	2.0
Fluorspar, Fine (Calcium Fluoride)	80-100	$90B_{6}36$	2D	2.0
Fluorspar, Lumps	90-110	$100D_{7}36$	2D	2.0
Flyash	30-45	$38A_{40}36M$	3D	2.0
Foundry Sand, Dry (See Sand)	—	—	—	—
Fullers Earth, Dry, Raw	30-40	$35A_{40}25$	2D	2.0
Fullers Earth, Oily, Spent	60-65	$63C_{1/2}45OW$	3D	2.0
Fullers Earth, Calcined	40	$40A_{100}25$	3D	2.0
Galena (See Lead Sulfide)	—	—	—	—
Gelatine, Granulated	32	$32B_{6}35PU$	1B	.8

Material	Weight lbs/ft³	Material Code	Component Series	Mat'l. Factor Fm
Gilsonite	37	37C½35	3D	1.5
Glass, Batch	80-100	90C½37	3D	2.5
Glue, Ground	40	40B$_6$45U	2D	1.7
Glue, Pearl	40	40C½35U	1A-1B-1C	.5
Glue, Veg Powdered	40	40A$_{40}$45U	1A-1B-1C	.6
Gluten, Meal	40	40B$_6$35P	1B	.6
Granite, Fine	80-90	85C½27	3D	2.5
Grape Pomace	15-20	18D$_3$45U	2D	1.4
Graphite Flake	40	40B$_6$25LP	1A-1B-1C	.5
Graphite Flour	28	28A$_{100}$35LMP	1A-1B-1C	.5
Graphite Ore	65-75	70D$_x$35L	2D	1.0
Guano Dry(¹)	70	70C½35	3A-3B	2.0
Gypsum, Calcined	55-60	58B$_6$35U	2D	1.6
Gypsum, Calcined, Powdered	60-80	70A$_{100}$35U	2D	2.0
Gypsum Raw — 1"	70-80	75D$_3$25	2D	2.0
Hay, Chopped(¹)	8-12	10C½35JY	2A-2B	1.6
Hexanedioic Acid (See Adipic Acid)	—	—	—	—
Hominy, Dry	35-50	43C½25D	1A-1B-1C	.4
Hops, Spent, Dry	35	35D$_3$35	2A-2B-2C	1.0
Hops, Spent, Wet	50-55	53D$_3$45V	2A-2B	1.5
Ice, Crushed	35-45	40D$_3$350	2A-2B	.4
Ice, Flaked(¹)	40-45	43C½350	1B	.6
Ice, Cubes	33-35	34D$_3$350	1B	.4
Ice, Shell	33-35	34D$_3$450	1B	.4
Ilmenite Ore	140-160	150D$_3$37	3D	2.0
Iron Ore Concentrate	120-180	150A$_{40}$37	3D	2.2
Iron Oxide Pigment	25	25A$_{100}$36LMP	1A-1B-1C	1.0
Iron Oxide, Millscale	75	75C½36	2D	1.6
Iron Pyrites (See Ferrous Sulfide)	—	—	—	—
Iron Sulphate (See Ferrous Sulfate)	—	—	—	—
Iron Sulfide (See Ferrous Sulfide)	—	—	—	—
Iron Vitriol (See Ferrous Sulfate)	—	—	—	—
Kafir (Corn)	40-45	43C½25	3D	.5
Kaolin Clay	63	63D$_3$25	2D	2.0
Kaolin Clay-Tale	42-56	49A$_{40}$35LMP	2D	2.0
Kryalith (See Cryolite)	—	—	—	—
Lactose	32	32A$_{40}$35PU	1B	.6
Lamp Black (See Carbon Black)	—	—	—	—
Lead Arsenate	72	72A$_{40}$35R	1A-1B-1C	1.4
Lead Arsenite	72	72A$_{40}$35R	1A-1B-1C	1.4
Lead Carbonate	240-260	250A$_{40}$35R	2D	1.0
Lead Ore — ⅛"	200-270	235B$_6$35	3D	1.4
Lead Ore — ½"	180-230	205C½36	3D	1.4
Lead Oxide (Red Lead) — 100 Mesh	30-150	90A$_{100}$35P	2D	1.2
Lead Oxide (Red Lead) — 200 Mesh	30-180	105A$_{200}$35LP	2D	1.2
Lead Sulphide — 100 Mesh	240-260	250A$_{100}$35R	2D	—
Lignite (See Coal Lignite)	—	—	—	—
Limanite, Ore, Brown	120	120C½47	3D	1.7
Lime, Ground, Unslaked	60-65	63B$_6$35U	1A-1B-1C	.6
Lime Hydrated	40	40B$_6$35LM	2D	.8
Lime, Hydrated, Pulverized	32-40	36A$_{40}$35LM	1A-1B	.6
Lime, Pebble	53-56	55C½25HU	2A-2B	2.0
Limestone, Agricultural	68	68B$_6$35	2D	2.0
Limestone, Crushed	85-90	88D$_x$36	2D	2.0
Limestone, Dust	55-95	75A$_{40}$46MY	2D	1.6-2.0
Lindane (Benzene Hexachloride)	—	—	—	—
Linseed (See Flaxseed)	—	—	—	—

Table 4 (cont'd) Material Characteristics

Material	Weight lbs/ft³	Material Code	Component Series	Mat'l. Factor Fm
Litharge (Lead Oxide)	—	—	—	—
Lithopone	45-50	$48A_{325}35MR$	1A-1B	1.0
Maize (See Milo)	—	—	—	—
Malt, Dry, Ground	20-30	$25B_635NP$	1A-1B-1C	.5
Malt, Meal	36-40	$38B_625P$	1A-1B-1C	.4
Malt, Dry Whole	20-30	$25C_{1/2}35N$	1A-1B-1C	.5
Malt, Sprouts	13-15	$14C_{1/2}35P$	1A-1B-1C	.4
Magnesium Chloride (Magnesite)	33	$33C_{1/2}45$	1A-1B	1.0
Manganese Dioxide(¹)	70-85	$78A_{100}35NRT$	2A-2B	1.5
Manganese Ore	125-140	$133D_737$	3D	2.0
Manganese Oxide	120	$120A_{100}36$	2D	2.0
Manganese Sulfate	70	$70C_{1/2}37$	3D	2.4
Marble, Crushed	80-95	$88B_637$	3D	2.0
Marl, (Clay)	80	$80D_736$	2D	1.6
Meat, Ground	50-55	53E45HQTX	2A-2B	1.5
Meat, Scrap (W/bone)	40	40E46H	2D	1.5
Mica, Flakes	17-22	$20B_616MY$	2D	1.0
Mica, Ground	13-15	$14B_636$	2D	.9
Mica, Pulverized	13-15	$14A_{100}36M$	2D	1.0
Milk, Dried, Flake	5-6	$6B_635PUY$	1B	.4
Milk, Malted	27-30	$29A_{40}45PX$	1B	.9
Milk, Powdered	20-45	$33B_625PM$	1B	.5
Milk Sugar	32	$32A_{100}35PX$	1B	.6
Milk, Whole, Powdered	20-36	$28B_635PUX$	1B	.5
Mill Scale (Steel)	120-125	123E46T	3D	3.0
Milo, Ground	32-36	$34B_625$	1A-1B-1C	.5
Milo Maize (Kafir)	40-45	$43B_615N$	1A-1B-1C	.4
Molybdenite Powder	107	$107B_626$	2D	1.5
Monosodium Phosphate	50	$50B_636$	2D	.6
Mortar, Wet(¹)	150	150E46T	3D	3.0
Mustard Seed	45	$45B_615N$	1A-1B-1C	.4
Naphthalene Flakes	45	$45B_635$	1A-1B-1C	.7
Niacin (Nicotinic Acid)	35	$35A_{40}35P$	2D	.8
Oats	26	$26C_{1/2}25MN$	1A-1B-1C	.4
Oats, Crimped	19-26	$23C_{1/2}35$	1A-1B-1C	.5
Oats, Crushed	22	$22B_645NY$	1A-1B-1C	.6
Oats, Flour	35	$35A_{100}35$	1A-1B-1C	.5
Oat Hulls	8-12	$10B_635NY$	1A-1B-1C	.5
Oats, Rolled	19-24	$22C_{1/2}35NY$	1A-1B-1C	.6
Oleo Margarine (Margarine)	59	59E45HKPWX	2A-2B	.4
Orange Peel, Dry	15	15E45	2A-2B	1.5
Oxalic Acid Crystals — Ethane Diacid Crystals	60	$60B_635QS$	1A-1B	1.0
Oyster Shells, Ground	50-60	$55C_{1/2}36T$	3D	1.6-2.0
Oyster Shells, Whole	80	$80D_336TV$	3D	2.1-2.5
Paper Pulp (4% or less)	62	62E45	2A-2B	1.5
Paper Pulp (6% to 15%)	60-62	61E45	2A-2B	1.5
Paraffin Cake — ½"	45	$45C_{1/2}45K$	1A-1B	.6
Peanuts, Clean, in shell	15-20	$18D_335Q$	2A-2B	.6
Peanut Meal	30	$30B_635P$	1B	.6
Peanuts, Raw, Uncleaned (unshelled)	15-20	$18D_336Q$	3D	.7
Peanuts, Shelled	35-45	$40C_{1/2}35Q$	1B	.4
Peas, Dried	45-50	$48C_{1/2}15NQ$	1A-1B-1C	.5
Perlite-Expanded	8-12	$10C_{1/2}36$	2D	.6
Phosphate Acid Fertilizer	60	$60B_625T$	2A-2B	1.4
Phosphate Disodium (See Sodium Phosphate)	—	—	—	—

(¹)Consult FMC

Table 4 (cont'd) Material Characteristics

Material	Weight lbs/ft³	Material Code	Component Series	Mat'l. Factor Fm
Phosphate Rock, Broken	75-85	80D,36	2D	2.1
Phosphate Rock, Pulverized	60	60$B_6$36	2D	1.7
Phosphate Sand	90-100	95$B_6$37	3D	2.0
Plaster of Paris (See Gypsum)	—	—	—	—
Plumbago (See Graphite)	—	—	—	—
Polystyrene Beads	40	40$B_6$35PQ	1B	4
Polyvinyl, Chloride Powder	20-30	25A_{100}45KT	2B	1.0
Polyvinyl, Chloride Pellets	20-30	25E45KPQT	1B	6
Polyethelene, Resin Pellets	30-35	33$C_{1/2}$45Q	1A-1B	4
Potash (Muriate) Dry	70	70$B_6$37	3D	2.0
Potash (Muriate) Mine Run	75	75D,37	3D	2.2
Potassium Carbonate	51	51$B_6$36	2D	1.0
Potassium Chloride Pellets	120-130	125$C_{1/2}$25TU	3D	1.6
Potassium Nitrate — ½"	76	76$C_{1/2}$16NT	3D	1.2
Potassium Nitrate — ⅛"	80	80$B_6$26NT	3D	1.2
Potassium Sulfate	42-48	45$B_6$46X	2D	1.0
Potato Flour	48	48A_{200}35MNP	1A-1B	5
Pumice — ⅛"	42-48	45$B_6$46	3D	1.6
Pyrite, Pellets	120-130	125$C_{1/2}$26	3D	2.0
Quartz, — 100 Mesh	70-80	75A_{100}27	3D	1.7
Quartz, — ½"	80-90	85$C_{1/2}$27	3D	2.0
Rice, Bran	20	20$B_6$35NY	1A-1B-1C	4
Rice, Grits	42-45	44$B_6$35P	1A-1B-1C	4
Rice, Polished	30	30$C_{1/2}$15P	1A-1B-1C	4
Rice, Hulled	45-49	47$C_{1/2}$25P	1A-1B-1C	4
Rice, Hulls	20-21	21$B_6$35NY	1A-1B-1C	4
Rice, Rough	32-36	34$C_{1/2}$35N	1A-1B-1C	6
Rosin — ½"	65-68	67$C_{1/2}$45Q	1A-1B-1C	1.5
Rubber, Reclaimed Ground	23-50	37$C_{1/2}$45	1A-1B-1C	8
Rubber, Pelleted	50-55	53$D_3$45	2A-2B-2C	1.5
Rye	42-48	45$B_6$15N	1A-1B-1C	4
Rye Bran	15-20	18$B_6$35Y	1A-1B-1C	4
Rye Feed	33	33$B_6$35N	1A-1B-1C	5
Rye Meal	35-40	38$B_6$35	1A-1B-1C	5
Rye Middlings	42	42$B_6$35	1A-1B	5
Rye, Shorts	32-33	33$C_{1/2}$35	2A-2B	5
Safflower, Cake	50	50$D_3$26	2D	6
Safflower, Meal	50	50$B_6$35	1A-1B-1C	6
Safflower Seed	45	45$B_6$15N	1A-1B-1C	4
Saffron (See Safflower)	—	—	—	—
Sal Animoniac (Ammonium Chloride)	—	—	—	—
Salt Cake, Dry Coarse	85	85$B_6$36TU	3D	2.1
Salt Cake, Dry Pulverized	65-85	75$B_6$36TU	3D	1.7
Salicylic Acid	29	29$B_6$37U	3D	6
Salt, Dry Coarse	45-60	53$C_{1/2}$36TU	3D	1.0
Salt, Dry Fine	70-80	75$B_6$36TU	3D	1.7
Saltpeter — (See Potassium Nitrate)	—	—	—	—
Sand Dry Bank (Damp)	110-130	120$B_6$47	3D	2.8
Sand Dry Bank (Dry)	90-110	100$B_6$37	3D	1.7
Sand Dry Silica	90-100	95$B_6$27	3D	2.0
Sand Foundry (Shake Out)	90-100	95$D_3$37Z	3D	2.6
Sand (Resin Coated) Silica	104	104$B_6$27	3D	2.0
Sand (Resin Coated) Zircon	115	115A_{100}27	3D	2.3
Sawdust, Dry	10-13	12$B_6$45UX	1A-1B-1C	7
Sea-Coal	65	65$B_6$36	2D	1.0
Sesame Seed	27-41	34$B_6$26	2D	6

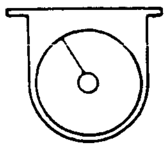
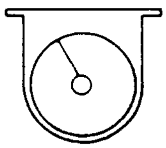
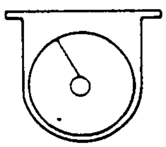
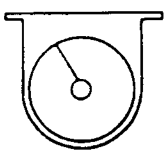
Table 4 (cont'd) Material Characteristics

Material	Weight lbs/ft³	Material Code	Component Series	Mat'l. Factor Fm
Shale, Crushed	85-90	$88C_{1/2}36$	2D	2.0
Shellac, Powdered or Granulated	31	$31B_{6}35P$	1B	.6
Silicon Dioxide (See Quartz)	—	—	—	—
Silica, Flour	80	$80A_{40}46$	2D	1.5
Silica Gel + ½"-3"	45	$45D_{3}37HKQU$	3D	2.0
Slag, Blast Furnace Crushed	130-180	$155D_{3}37Y$	3D	2.4
Slag, Furnace Granular, Dry	60-65	$63C_{1/2}37$	3D	2.2
Slate, Crushed, – ½"	80-90	$85C_{1/2}36$	2D	2.0
Slate, Ground, – ⅛"	82-85	$84B_{6}36$	2D	1.6
Sludge, Sewage, Dried	40-50	45E47TW	3D	.8
Sludge, Sewage, Dry Ground	45-55	50B46S	2D	.8
Soap, Beads or Granules	15-35	$25B_{6}35Q$	1A-1B-1C	.6
Soap, Chips	15-25	$20C_{1/2}35Q$	1A-1B-1C	.6
Soap Detergent	15-50	$33B_{6}35FQ$	1A-1B-1C	.8
Soap, Flakes	5-15	$10B_{6}35QXY$	1A-1B-1C	.6
Soap, Powder	20-25	$23B_{6}25X$	1A-1B-1C	.9
Soapstone, Talc, Fine	40-50	$45A_{200}45XY$	1A-1B-1C	2.0
Soda Ash, Heavy	55-65	$60B_{6}36$	2D	1.0
Soda Ash, Light	20-35	$28A_{40}36Y$	2D	.8
Sodium Aluminate, Ground	72	$72B_{6}36$	2D	1.0
Sodium Aluminum Fluoride (See Kryolite)	—	—	—	—
Sodium Aluminum Sulphate(1)	75	$75A_{100}36$	2D	1.0
Sodium Bentonite (See Bentonite)	—	—	—	—
Sodium Bicarbonate (See Baking Soda)	—	—	—	—
Sodium Chloride (See Salt)	—	—	—	—
Sodium Carbonate (See Soda Ash)	—	—	—	—
Sodium Hydrate (See Caustic Soda)	—	—	—	—
Sodium Hydroxide (See Caustic Soda)	—	—	—	—
Sodium Borate (See Borax)	—	—	—	—
Sodium Nitrate	70-80	$75D_{3}25NS$	2A-2B	1.2
Sodium Phosphate	50-60	55A35	1A-1B	.9
Sodium Sulfate (See Salt Cake)	—	—	—	—
Sodium Sulfite	96	$96B_{6}46X$	2D	1.5
Sorghum, Seed (See Kafir or Milo)	—	—	—	—
Soybean, Cake	40-43	$42D_{3}35W$	2A-1B-1C	1.0
Soybean, Cracked	30-40	$35C_{1/2}36NW$	2D	.5
Soybean, Flake, Raw	18-25	$22C_{1/2}35Y$	1A-1B-1C	.8
Soybean, Flour	27-30	$29A_{40}35MN$	1A-1B-1C	.8
Soybean Meal, Cold	40	$40B_{6}35$	1A-1B-1C	.5
Soybean Meal, Hot	40	$40B_{6}35T$	2A-2B	.5
Soybeans, Whole	45-50	$48C_{1/2}26NW$	—	1.0
Starch	25-50	$38A_{40}15M$	1A-1B-1C	1.0
Steel Turnings, Crushed	100-150	$125D_{3}46WV$	3D	3.0
Sugar Beet, Pulp, Dry	12-15	$14C_{1/2}26$	2D	.9
Sugar Beet, Pulp, Wet	25-45	$35C_{1/2}35X$	1A-1B-1C	1.2
Sugar, Refined, Granulated Dry	50-55	$53B_{6}35PU$	1B	1.0-1.2
Sugar, Refined, Granulated Wet	55-65	$60C_{1/2}35X$	1B	1.4-2.0
Sugar, Powdered	50-60	$55A_{100}35PX$	1B	.8
Sugar, Raw	55-65	$60B_{6}35PX$	1B	1.5
Sulphur, Crushed – ½"	50-60	$55C_{1/2}35N$	1A-1B	.8
Sulphur, Lumpy, – 3"	80-85	$83D_{3}35N$	2A-2B	.8
Sulphur, Powdered	50-60	$55A_{40}35MN$	1A-1B	.6
Sunflower Seed	19-38	$29C_{1/2}15$	1A-1B-1C	.5
Talcum, – ½"	80-90	$85C_{1/2}36$	2D	.9
Talcum Powder	50-60	$55A_{200}36M$	2D	.8
Tanbark, Ground(1)	55	$55B_{6}45$	1A-1B-1C	.7

Table 4 (cont'd) Material Characteristics

Material	Weight lbs/ft^3	Material Code	Component Series	Mat'l. Factor Fm
Timothy Seed	36	$36B_635NY$	1A-1B-1C	.6
Titanium Dioxide (See Ilmenite Ore)	—	—	—	—
Tobacco, Scraps	15-25	$20D_345Y$	2A-2B	.8
Tobacco, Snuff	30	$30B_645MQ$	1A-1B-1C	.9
Tricalcium Phosphate	40-50	$45A_{40}45$	1A-1B	1.6
Triple Super Phosphate	50-55	$53B_636RS$	3D	2.0
Trisodium Phosphate	60	$60C_{1/2}36$	2D	1.7
Trisodium Phosphate, Granular	60	$60B_636$	2D	1.7
Trisodium Phosphate, Pulverized	50	$50A_{40}36$	2D	1.6
Tung Nut Meats, Crushed	28	$28D_325W$	2A-2B	.8
Tung Nuts	25-30	$28D_315$	2A-2B	.7
Urea Polls, Coated	43-46	$45B_625$	1A-1B-1C	1.2
Vermiculite, Expanded	16	$16C_{1/2}35Y$	1A-1B	.5
Vermiculite, Ore	80	$80D_336$	2D	1.0
Vetch	48	$48B_616N$	1A-1B-1C	.4
Walnut Shells, Crushed	35-45	$40B_636$	2D	1.0
Wheat	45-48	$47C_{1/2}25N$	1A-1B-1C	.4
Wheat, Cracked	40-45	$43B_625N$	1A-1B-1C	.4
Wheat, Germ	18-28	$23B_625$	1A-1B-1C	.4
White Lead, Dry	75-100	$88A_{40}36MR$	2D	1.0
Wood Chips, Screened	10-30	$20D_345VY$	2A-2B	.6
Wood Flour	16-36	$26B_635N$	1A-1B	.4
Wood Shavings	8-16	12E45VY	2A-2B	1.5
Zinc, Concentrate Residue	75-8	$78B_637$	3D	1.0
Zinc Oxide, Heavy	30-35	$33A_{100}45X$	1A-1B	1.0
Zinc Oxide, Light	10-15	$13A_{100}45XY$	1A-1B	1.0

Table 5 Horizontal Screw Conveyor Capacity*

Material Class Code	Degree of Trough Loading	Screw Dia Inches	Maximum Recommended rpm	Capacity Cubic Feet Per Hour	
				At Max rpm	At One rpm
A-15		6	165	368	2.23
A-25		9	155	1270	8.2
B-15	45%				
B-25		12	145	2820	19.4
C-15		14	140	4370	31.2
C-25					
		16	130	6060	46.7
		18	120	8120	67.6
		20	110	10300	93.7
		24	100	16400	164.0
A-35 E-35		6	120	180	1.49
A-45 E-45		9	100	545	5.45
B-35	30%	12	90	1160	12.9
B-45	A	14	85	1770	20.8
C-35					
C-45					
D-15					
D-25					
D-35		16	80	2500	31.2
D-45		18	75	3380	45.0
E-15		20	70	4370	62.5
E-25		24	65	7100	109.0
A-16 D-16		6	60	90	1.49
A-26 D-26		9	55	300	5.45
A-36 D-36	30%	12	50	645	12.9
A-46 D-46	B	14	50	1040	20.8
B-16 E-16					
B-26 E-26					
B-36 E-36					
B-46 E-46					
C-16		16	45	1400	31.2
C-26		18	45	2025	45.0
C-36		20	40	2500	62.5
C-46		24	40	4360	109.0
A-17 D-17		6	60	45	0.75
A-27 D-27		9	55	150	2.72
A-37 D-37	15%	12	50	325	6.46
A-47 D-47		14	50	520	10.4
B-17 E-17					
B-27 E-27					
B-37 E-37					
B-47 E-47					
C-17		16	45	700	15.6
C-27		18	45	1010	22.5
C-37		20	40	1250	31.2
C-47		24	40	2180	54.6

*For capacities of inclined screw conveyors, contact FMC

Table 7 Maximum Lump Size

Screw Dia	Pipe O.D.	Radial Clearance	Class I 10% Lumps Ratio R. = 1.75 Max Lump Inch	Class II 25% Lumps Ratio R = 2.5 Max Lump Inch	Class III 95% Lumps Ratio R. = 4.5 Max Lump Inch
Inches*					
6	2⅜	2 5/16	1¼	¾	½
9	2⅜	3 13/16	2¼	1½	¾
9	2⅞	3 9/16	2¼	1½	¾
12	2⅞	5 1/16	2¾	2	1
12	3½	4¾	2¾	2	1
12	4	4½	2¾	2	1
14	3½	5¾	3¼	2½	1¼
14	4	5½	3¼	2½	1¼
16	4	6½	3¾	2¾	1½
16	4½	6¼	3¾	2¾	1½
18	4	7½	4¼	3	1¾
18	4½	7¼	4¼	3	1¾
20	4	8½	4¾	3½	2
20	4½	8¼	4¾	3½	2
24	4½	10¼	6	3¾	2½

Table 8 Component Group Selection Guide

Material Classification Code				Component Group Designation				
				Group Number Designation	Type of Intermediate Hanger Bearing[3] See Table 12			
Material Size Classification		Abrasiveness Number	Corrosiveness Letter		Babbitted or Bronze	Self Lubricating	Ball Bearing [2]	Hard Iron
A_{200} A_{100} A_{40}	B_6 $C_{1/2}$	5	Non-Corr. T S	1 2 3	A A A	B B B	C — —	— — —
D_3 D_2 D_{16} D_x	or E	5	Non-Corr. T S	2 2 3	A A A	B B B	C — —	— — —
A_{200} A_{100} A_{40}	B_6 $C_{1/2}$	6	Non-Corr. T S	2 3 3(1)	— — —	— — —	— — —	D D D
D_3 D_7 D_{16} D_x	or E	6	Non-Corr. T S	2 3 3(1)	— — —	— — —	— — —	D D D
A_{200} A_{100} A_{40}	B_6 $C_{1/2}$	7	Non-Corr. T S	3 3 3(1)	— — —	— — —	— — —	D D D
D_3 D_7 D_{16} D_x	or E	7	Non-Corr. T S	3 3 3(1)	— — —	— — —	— — —	D D D

(1)For very corrosive conditions (codes 6S or 7S) lighter gauge special anti-corrosion materials may be used.

Table 12 Recommended Hanger Bearings and Coupling Shafts

Component Group	Bearing Type	Coupling
Group A	Ball	Standard
Group B	Babbitt Bronze (¹)Graphite bronze (¹)Canvas base phenolic (¹)Oil Impregnated bronze (¹)Oil Impregnated wood	Standard
Group C	(¹)Plastic (¹)Nylon (¹)Teflon	Standard
Group D	(¹)Chilled hard iron (¹)Hardened alloy sleeve	Hardened

(¹)Nonlubricated bearings, or bearings not additionally lubricated

Table 13 Hanger Bearing Factor, F_b

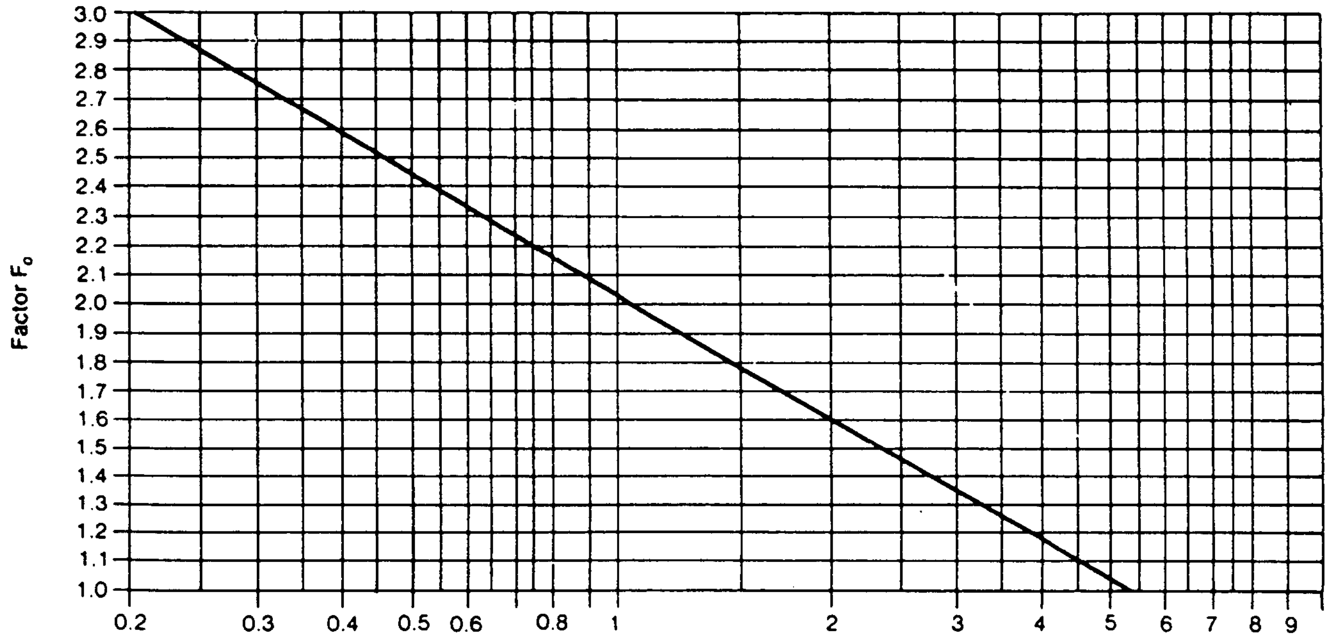
Component Group	Bearing Type	F_b
Group A	Ball	1.0
Group B	Babbitt Bronze (¹)Graphite bronze (¹)Canvas base phenolic (¹)Oil Impregnated bronze (¹)Oil Impregnated wood	1.7
Group C	(¹)Plastic (¹)Nylon (¹)Teflon	2.0
Group D	(¹)Chilled hard iron (¹)Hardened alloy sleeve	4.4

(¹)Nonlubricated bearings, or bearings not additionally lubricated.

Table 14 Screw Diameter Factor, F_d

Screw Diameter Inches	F_d	Screw Diameter Inches	F_d
4	12.0	14	78.0
6	18.0	16	106.0
9	31.0	18	135.0
10	37.0	20	165.0
12	55.0	24	235.0

F_o – OVERLOAD FACTOR



HORSEPOWER $HP_f + HP_m$

FOR VALUES OF $HP_f + HP_m$ GREATER THAN 5.2, F_o IS 1.0

TRACE THE VALUE OF ($HP_f + HP_m$) VERTICALLY TO THE DIAGONAL LINE, THEN ACROSS TO THE LEFT WHERE THE F_o VALUE IS LISTED.

Figure D

Table 15 Torsional Ratings of Bolts, Pipe and Coupling In. Lbs.

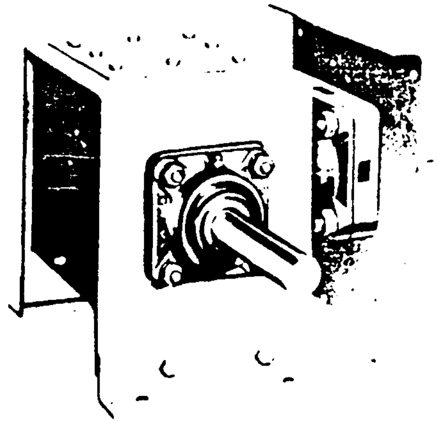
Shaft Dia	Pipe		Couplings		Bolts				
	Size	Torque In Lbs	Torque In. Lbs		Dia	Bolts in Shear T_1 In Lbs		Bolts in Bearing T_2 In Lbs	
			Std	Hard		Number of Bolts Used			
Inches		T_3	T_4	T_5	Inches	2	3	2	3
1	1¼	3,140	820[1]	1,025	⅜	1,380	2,070	1,970	2,955
1½	2	7,500	3,070[1]	3,850	½	3,660	5,490	5,000	7,500
2	2½	14,250	7,600[1]	9,500	⅝	7,600	11,400	7,860	11,790
2⁷⁄₁₆	3	23,100	15,090	18,900	⅝	9,270[1]	13,900	11,640	17,460
3	3½	32,100	28,370	35,400	¾	16,400	24,600	15,540[1]	23,310
3	4	43,000	28,370	35,400	¾	16,400[1]	24,600	25,000	37,500
3⁷⁄₁₆	4	43,000	42,550	53,000	⅞	25,600	38,400	21,800[1]	32,700

[1]Limiting Torsional Strength

Table 17 Equivalent Length of Feeder, L_f

Material Code Class	Maximum Particle Size Inches	Flight Type Under Inlet	Values of Lf Feet For Dimensions See Figures F & G, page B-46
A15, A16, A17, A25, A26, A27, A35, A36, A37.	⅛	Standard pitch Uniform dia. Short pitch Uniform dia.	$L_1 + \frac{B}{6} + \frac{C}{12}$ B & C from Table 16, page 33
B15, B16, B17, B25, B26, B27, B35, B36, B37.	⅛	Standard pitch [1]Tapered dia. Short pitch [1]Tapered dia.	

[1]Variable pitch of constant diameter may be used in place of tapered diameter and constant pitch flighting.



✓Enclosed countershaft trough end

figure X

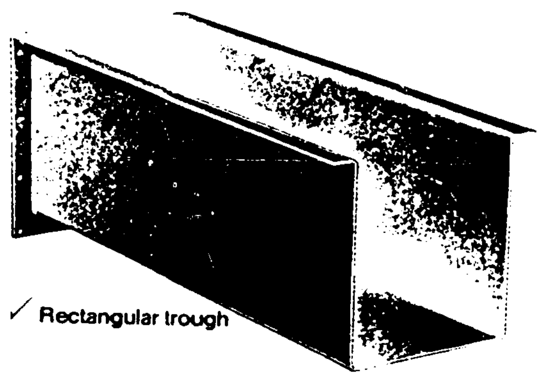


figure Y

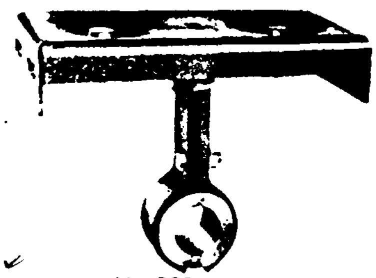
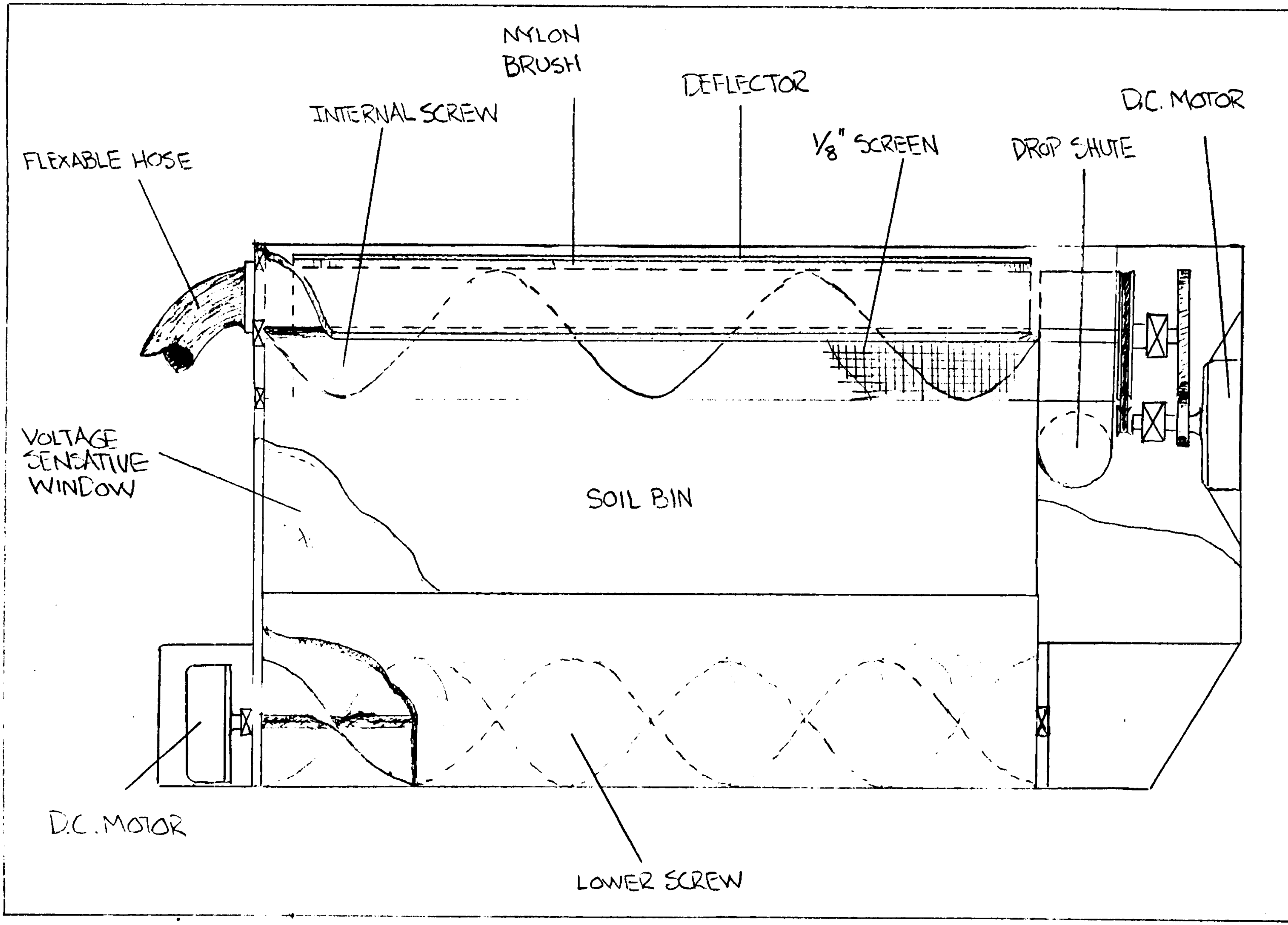
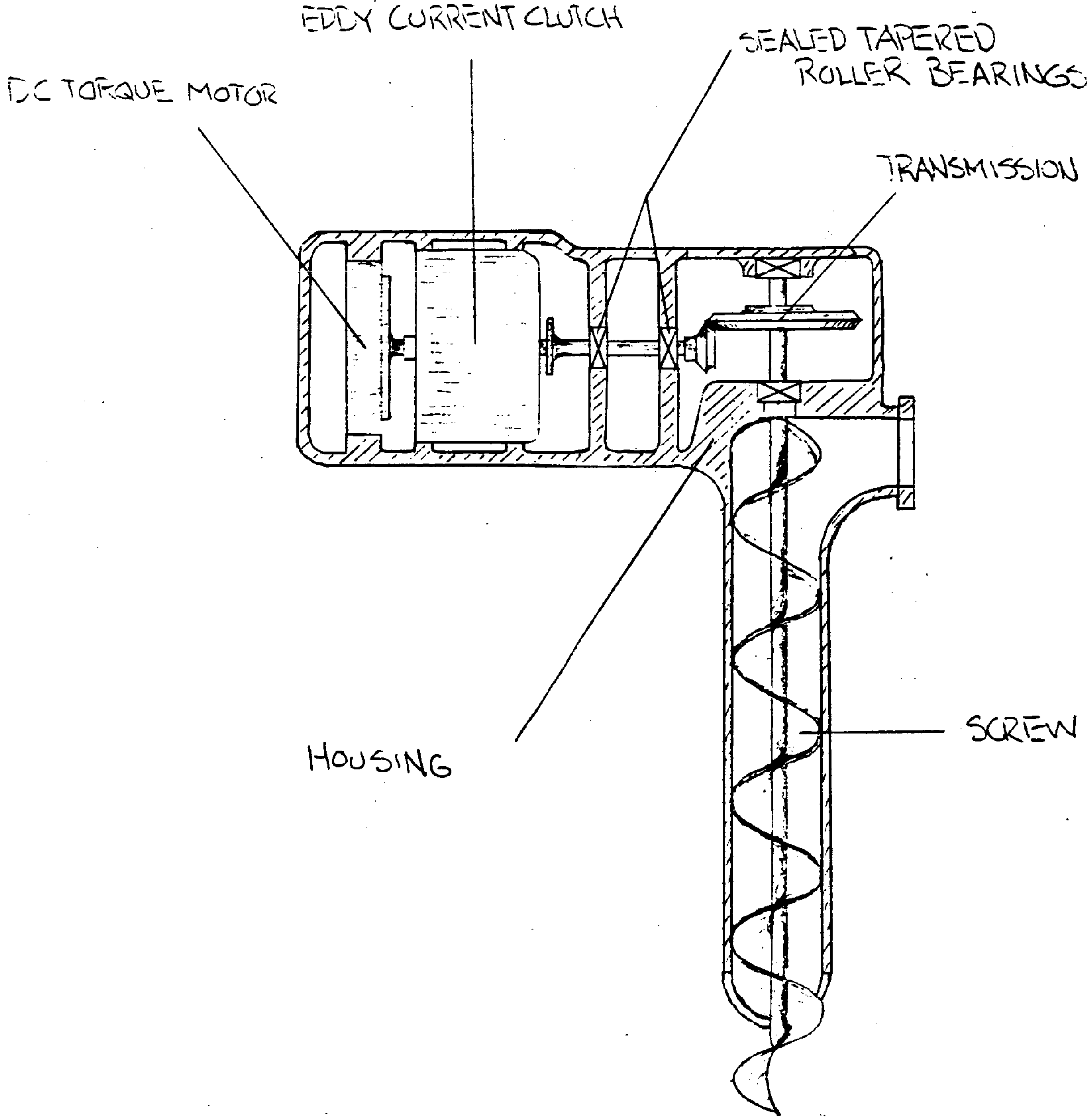

No. 226 hanger
with hard iron bearing

figure 2


NYLON BRUSH
DEFLECTOR
INTERNAL SCREW
D.C. MOTOR
FLEXABLE HOSE
1/8" SCREEN
DROP SHUTE
VOLTAGE SENSATIVE WINDOW
SOIL BIN
D.C. MOTOR
LOWER SCREW


EDDY CURRENT CLUTCH
SEALED TAPERED
ROLLER BEARINGS
DC TORQUE MOTOR
TRANSMISSION
SCREW
HOUSING

SCREW PUMP

CALCULATIONS

$$L_f = L_1 + \frac{B}{6} + \frac{C}{12}$$

$L_1 = 7$ FT.
$B = 36$
$C = 12$

$$L_f = 7 + \frac{36}{6} + \frac{12}{12}$$

$= 14$ FT.

$$HP_a = \frac{L_1 N F_d F_b}{1{,}000{,}000} = \frac{7(48)(18)(4.4)}{1{,}000{,}000} = .027$$

$$HP_b = \frac{C W L_f F_m}{1{,}000{,}000} = \frac{36(125)(14)(2.8)}{1{,}000{,}000} = .176$$

$$HP = \frac{(HP_a + HP_b) F_o}{e} = \frac{(.027 + .176)(3.0)}{.75} = .81 \text{ Hp.}$$

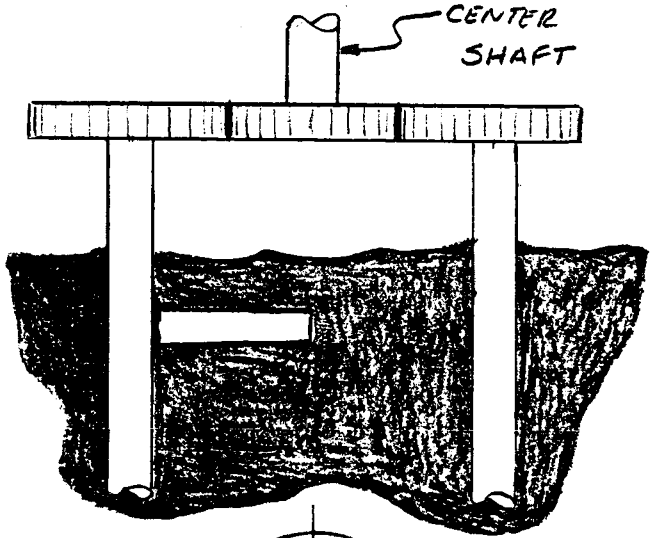
$$T_o = \frac{63025 \times Hp}{N} = \frac{63025}{48} = 1313 \text{ IN} \cdot \text{lbs}$$

APPENDIX B

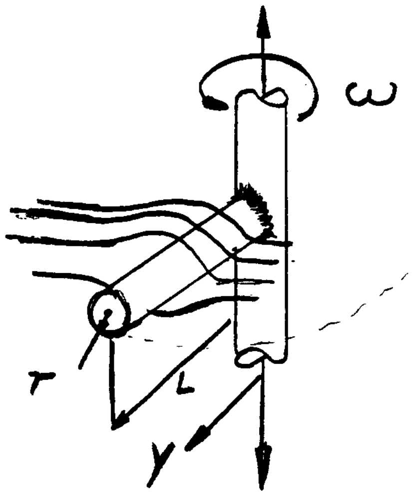
Mixing

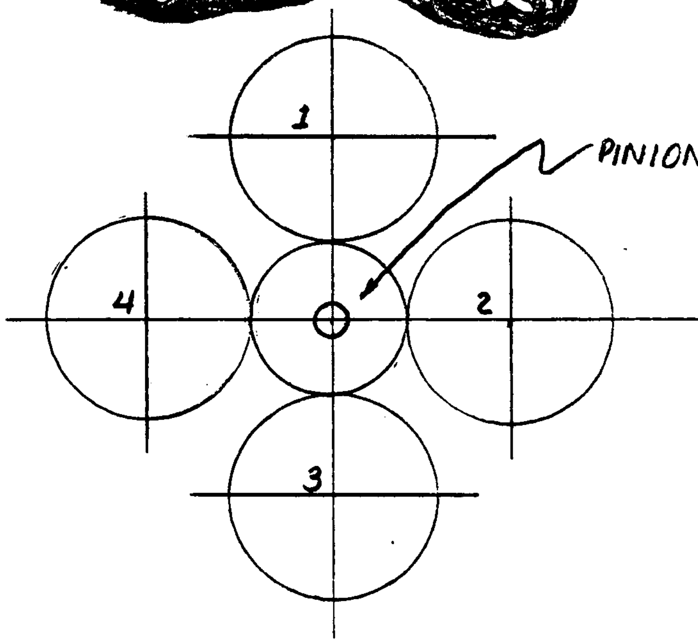
Shaft Size Determination

SIDE VIEW



ONE AGITATOR OF 80 IS SHOWN IN SIDE VIEW. PINION WILL DRIVE FOUR OUTTER GEARS. EACH OUTTER GEAR DRIVES A SHAFT CARRYING 20 AGITATORS.





TOP VIEW

AS AGITATOR IS ROTATED, MATERIAL EXERTS A FORCE AGAINST EACH AGITATOR. THIS FORCE IS GIVEN BY:

$$D = \frac{1}{2} C_D \rho V^2 A \quad \text{WHERE}$$

C_D = DRAG COEFFICIENT

ρ = DENSITY OF SLUDGE

V = VELOCITY OF AGITATOR

A = TOTAL SURFACE AREA OF AGITATOR

THIS FORCE CREATES A MOMENT ABOUT THE ROTATING SHAFT. THIS MOMENT IS GIVEN BY:

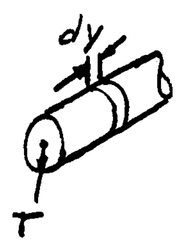
$$M = Dy = \frac{1}{2} C_D \rho V^2 A y$$

WHERE y IS RADIAL DISTANCE FROM CENTER OF ROTATING SHAFT.
BECAUSE MOMENT AND VELOCITY VARY WITH DISTANCE FROM CENTER OF ROTATION, INTEGRATION MUST BE PERFORMED.

$$M = \int_L \frac{1}{2} C_D \rho V^2 A y$$

$V = \omega y$; ω = ROTATIONAL VELOCITY

$A = 2\pi r\, dy$; r = RADIUS OF AGITATOR



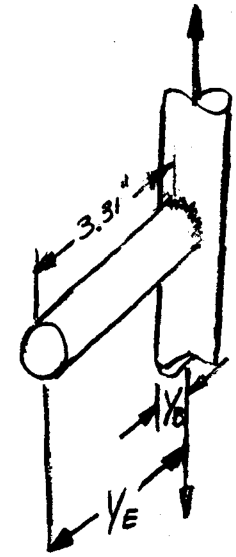
BY SUBSTITUTION

$$M = \int_L \frac{1}{2} C_D \rho (\omega y)^2 2\pi r\, dy\, y$$

$$M = C_D \rho \omega^2 \pi r \int_L y^3 dy$$

$$M = C_D \rho \omega^2 \pi r (y^4/4)\Big|_L$$

$Re = \frac{\bar{V} d}{\nu}$ WHERE



$\bar{V}$ = AVERAGE VELOCITY

$= \omega (y_B + y_E)/2$

$d = 2r$

ν = VISCOSITY OF MATERIAL

$\omega = (30 \text{ RPM})(2\pi)\left(\frac{1 \text{ MIN}}{60 \text{ SEC}}\right)$

$= 3.1416$ RAD/SEC

$y_B = .026$ FT.

$y_E = .3018$ FT.

$\bar{V} = (3.1416 \text{ RAD/SEC})(.026 \text{ FT} + .3018 \text{ FT.})/2$

$= .5151$ FT/SEC

$d = 2r = 2(.0156 \text{ FT})$

$= .03125$ FT

$\nu \approx 10^{-2}$ FT^2/SEC

$Re = \frac{(.5151 \text{ FT/SEC})(.03125 \text{ FT})}{10^{-2} \text{ FT}^2/\text{SEC}}$

$= 1.61$

THIS VALUE YIELDS A DRAG COEFFICIENT

$C_D \approx 22$

DENSITY OF LUNAR MATERIAL WAS TAKEN TO BE

$$\rho = 93.64 \ lb_m / FT^3$$

So,

$$M = C_D \rho \omega^2 \pi r \left(y^4/4 \right) \Big|_{y = y_B = .026 \ FT}^{y = y_E = .3018 \ FT}$$

$$= (22)(93.64 \ lb_m/FT^3)(3.1416 \ RAD/SEC)^2 \pi \left(\frac{lb_f}{5.37 \ lb_m ft/sec^2} \right)$$

$$\cdot (.0156 \ FT) \left(\frac{(.3018)^4 - (.026)^4}{4} \right)$$

$$M = .371 \ FT \cdot lb_f$$

FOR EACH AGITATOR THERE IS .371 FT·lb$_f$ OF TORQUE EXERTED ON THE DRIVING SHAFT. SINCE A SINGLE SHAFT CARRIES 20 AGITATORS, THEN THE TOTAL TORQUE UPON THE SHAFT IS

$$= 20(.371 \ FT \cdot lb_f)$$

$$= 7.42 \ FT \cdot lb_f$$

$$= 89.04 \ IN \cdot lb_f$$

SHEAR STRESS,

$$\tau = \frac{Tr}{J} \quad \text{WHERE}$$

T = APPLIED TORQUE

r = RADIUS OF SHAFT ; $d = 2r$

$J = \pi d^4 / 32$

$$\tau = \frac{T(d/2)}{\frac{\pi d^4}{32}}$$

MANIPULATING,

$$d = \left(\frac{T\,16}{\pi\,\tau}\right)^{1/3}$$

USE G 41400 STEEL
SHEAR STRESS = 131,000 lb/IN

$$d = \left[\frac{(89.04\ \text{IN}\cdot\text{lb}_f)\,16}{\pi\left(131{,}000\ \frac{\text{lb}_f}{\text{IN}^2}\right)}\right]^{1/3}$$

$$= .15129\ \text{IN}$$

FOR SAFETY FACTOR OF 5

$d = .258"$ FOR FOUR DRIVING SHAFTS.

TORQUE ON CENTRAL SHAFT IS

$$T = \left(\frac{3}{4}\right)(89.07\ \text{IN}\cdot\text{lb}_f)$$

$$= 66.8\ \text{IN}\cdot\text{lb}_f$$

DELIVERED BY ONE OF THE
FOUR DRIVERS

THEREFORE, TOTAL TORQUE EXERTED ON CENTRAL SHAFT IS

$$= 4\,(66.8 \text{ IN}\cdot\text{lb}_f)$$
$$= 267 \text{ IN}\cdot\text{lb}_f$$

USING A SAFETY FACTOR OF 1.5 YIELDS A REQUIRED INPUT TORQUE OF

$$400 \text{ IN}\cdot\text{lb}_f$$

FOR THE CENTRAL INPUT SHAFT

$$d = \left(\frac{T\,16}{\pi\,\tau}\right)^{1/3}$$

$$= \left[\frac{(267.23 \text{ IN}\cdot\text{lb}_f)(16)}{\pi\left(131{,}000 \frac{\text{lb}_f}{\text{IN}^2}\right)}\right]^{1/3}$$

$$d = .218 \text{ IN}$$

USING A SAFETY FACTOR OF 5

$$d = .373''$$

Volume Calculation

VOLUME OF MIXTURE $= \pi r^2 h$

$$h = \frac{\text{VOLUME}}{\pi r^2}$$

$$= \frac{(1.2 + .012 + .108)\ ft^3}{\pi\ (.625\ ft)^2}$$

$$= 1.07\ ft$$

$$= 12.907\ in$$

VOLUME OF EACH SHAFT $= \pi r^2 h$

$$= \pi (.188\ in)^2 (12.907\ in)$$

$$= 1.433\ in^3$$

VOLUME OF 4 SHAFTS $= 4\,(1.433\ in^3)$

$$= 5.732\ in^3$$

VOLUME OF EACH SPIKE $= \pi r^2 h$

$$= \pi (.188\ in)^2 (3.56\ in)$$

$$= 0.395\ in^3$$

VOLUME OF 80 SPIKES $= (80)(.395\ in^3)$

$$= 31.623\ in^3$$

TOTAL VOLUME OF STIRRERS $= 5.732\ in^3 + 31.623\ in^3$

$$= 37.355\ in^3$$

HEIGHT RAISED $= \dfrac{\text{VOLUME}}{\pi r^2}$

$$= \frac{37.355}{\pi (7.5\ in)^2}$$

$$= 0.211\ in$$

RADIUS OF PINION (r_p) = 1.5 in

NUMBER OF TEETH ON PINION (N_p) = 18

RADIUS OF GEAR (r_G) = 2.0 in

NUMBER OF TEETH ON GEAR (N_G) = 24

PITCH (P) = 6 teeth/in

PRESSURE ANGLE (α) = 20°

FOR STANDARD PAIR OF GEARS $K_p = K_G = 1$

ADDENDUM AND DEDENDUM MEASUREMENTS

$$a = \frac{1}{P} = \frac{1}{6} = .167 \text{ in}$$

$$b = \frac{1.25}{P} = \frac{1.25}{6} = .208 \text{ in}$$

RADII OF ADDENDUM AND DEDENDUM CIRCLES

PINION

$$r_{a_p} = 1.50 + .167 = 1.667$$

$$r_{d_p} = 1.50 - .208 = 1.292$$

GEAR

$$r_{aG} = 2.00 + .167 = 2.167$$

$$r_{dG} = 2.00 + .208 = 2.208$$

CONTACT RATIO

$$m = \frac{\text{LENGTH OF ACTION LINE}}{\text{BASE PITCH}} = \frac{bf + fe}{p_b}$$

$$f_e = \frac{1}{2P}\left[\sqrt{(N_G \sin\alpha)^2 + 4K_G(N_G + K_G)} - N_G \sin\alpha\right.$$

$$= \frac{1}{2(6)}\left[\sqrt{(24 \sin 20^\circ)^2 + 4(1)(24+1)} - 24 \sin 20^\circ\right.$$

$$= 0.394$$

$$b_f = \frac{1}{2P}\left[\sqrt{(N_p \sin\alpha)^2 + 4K_p(N_p + K_p)} - N_p \sin\alpha\right.$$

$$= \frac{1}{2(6)}\left[\sqrt{(18 \sin 20^\circ)^2 + 4(1)(18+1)} - 18 \sin 20^\circ\right.$$

$$= 0.376$$

$$p_b = p \cos\alpha$$

$$= \frac{\pi}{P} \cos\alpha$$

$$= \left(\frac{\pi}{6}\right)\cos 20^\circ$$

$$= 0.492$$

$$m = \frac{0.376 + 0.394}{0.492}$$

$$= 1.565$$

Gear Size Determination

(1) HORSEPOWER = .25 hp
(2) SPEED RATIO = 1.333
(3) RPM OF PINION = 30 rpm
(4) PRESSURE ANGLE = 20 DEGREES
(5) TYPE OF TEETH : CUT / MILLED
(6) RELIABILITY (FATIGUE) : 99 %
(7) RELIABILITY (SURFACE DURABILITY) : 99 %
(8) LIFETIME = 10000 hr
(9) TEMPERATURE = 25 DEGREES
(10) SHOCK IN SOURCE : UNIFORM
(11) SHOCK ON MACHINERY : UNIFORM
(12) TYPE OF SUPPORT : AVERAGE
(13) YIELD STRENGTH OF PINION = 131 kpsi
(14) ULTIMATE STRENGTH OF PINION = 131 kpsi
(15) BRINELL HARDNESS OF PINION = 300
(16) YOUNG'S MODULUS OF PINION = 30 Mpsi
(17) POISSON'S RATIO OF PINION = .292
(18) YOUNG'S MODULUS OF GEAR = 30 Mpsi
(19) POISSON'S RATIO OF GEAR = .292
(20) (U)NIDIRCTIONAL OR (B)DIRECTIONAL DRIVE :U

PINION GEAR :

PITCH = 5.999996 TEETH / IN
NUMBER OF TEETH = 18
PITCH DIAMETER = 3.000002 IN
LINE VELOCITY = 23.56196 FPM
LOAD = 350.1407 LBF
FACE WIDTH = 1.662239 IN
MAXIMUM FACE WIDTH = 2.617996 IN
MINIMUM FACE WIDTH = 1.570797 IN

	SAFETY FACTOR
STATIC LOADING :	30.49634
FATIGUE LOADING :	7.999999
SURFACE DURABILITY :	2.903289

```
10 CLS:REM  SETUP MENU
20 PRINT:PRINT:PRINT:PRINT
30 PRINT TAB(15)"SPUR GEAR DESIGN PROGRAM"
40 PRINT:PRINT:PRINT
50 PRINT TAB(21)"MAIN MENU"
60 PRINT:PRINT:PRINT "  (0)  EXIT THE PROGRAM"
70 PRINT "  (1)  STATIC LOAD DESIGN"
80 PRINT "  (2)  FATIGUE LOAD DESIGN"
90 PRINT "  (3)  SURFACE DURABILITY DESIGN"
100 PRINT:PRINT:PRINT
110 INPUT "SELECT PRIMARY DESIGN CONSIDERATION";Q
120 PI = 3.14159265#
130 IF Q = 0 THEN CLS:END
140 IF Q < 1 OR Q > 3 OR Q <> INT(Q) THEN 10
150 CLS
160 REM  GET INPUTS
170 FOR COUNT = 1 TO 7:PRINT:NEXT COUNT
180 PRINT "MENU FOR ENTERING DATA"
190 PRINT:PRINT:PRINT "   (0)  RETURN TO MAIN MENU"
200 PRINT "   (1)  ENTERING NEW DATA"
210 PRINT "   (2)  REVIEWING OLD DATA"
220 PRINT "   (3)  EXECUTE PROGRAM"
230 PRINT:PRINT:PRINT:INPUT"CHOOSE AN OPTION";Q2
240 IF Q2 = 0 THEN 10
250 IF Q2 = 1 THEN 540
260 IF Q2 = 2 THEN 290
270 IF Q2 = 3 THEN 1170
280 GOTO 150
290 CLS:PRINT "(1) HORSEPOWER =";H;"hp"
300 PRINT "(2) SPEED RATIO =";MG
310 PRINT "(3) RPM OF PINION =";N;"rpm"
320 PRINT "(4) PRESSURE ANGLE =";THI;"DEGREES"
330 PRINT "(5) TYPE OF TEETH : ";TT$(TT)
340 PRINT "(6) RELIABILITY (FATIGUE) :";RELP;"%"
350 PRINT "(7) RELIABILITY (SURFACE DURABILITY) :";RELSP;"%"
360 PRINT "(8) LIFETIME =";HOUR;"hr"
370 PRINT "(9) TEMPERATURE =";TEMP;"DEGREES"
380 PRINT "(10) SHOCK IN SOURCE : ";PS$(PS1)
390 PRINT "(11) SHOCK ON MACHINERY : ";DMS$(DMS1)
400 PRINT "(12) TYPE OF SUPPORT : ";CSP$(CSUPP)
410 PRINT "(13) YIELD STRENGTH OF PINION =";SYK;"kpsi"
420 PRINT "(14) ULTIMATE STRENGTH OF PINION =";SUTK;"kpsi"
430 PRINT "(15) BRINELL HARDNESS OF PINION =";HB
440 PRINT "(16) YOUNG'S MODULUS OF PINION =";EPM;"Mpsi"
450 PRINT "(17) POISSON'S RATIO OF PINION =";UP
460 PRINT "(18) YOUNG'S MODULUS OF GEAR =";EGM;"Mpsi"
```

```
470 PRINT "(19) POISSON'S RATIO OF GEAR =";UG
480 PRINT "(20) (U)NIDIRCTIONAL OR (B)DIRECTIONAL DRIVE :";GD$
490 PRINT:INPUT "WHICH NUMBER TO CHANGE ( <CR> MEANS NONE )";QU
500 QU = INT(QU):IF QU = 0 THEN 150
510 CLS:CH$ = "Y"
520 ON QU GOSUB 550,570,590,610,660,720,740,760,790,810,810,930,1000,1020,1040,1
060,1080,1100,1120,1130
530 CH$ = "N":QU = 0:GOTO 290
540 CLS
550 INPUT "REQUIRED HORSEPOWER (hp)";H
560 IF CH$ = "Y" THEN RETURN
570 INPUT "SPEED RATIO (Ngear/Npinion)";MG
580 IF CH$ = "Y" THEN RETURN
590 INPUT "REQUIRED SPEED OF PINION (rpm)";N
600 IF CH$ = "Y" THEN RETURN
610 INPUT "PRESSURE ANGLE (20 OR 25)";THI
620 IF THI = 20 THEN NT = 18:GOTO 650
630 IF THI = 25 THEN NT = 12:GOTO 650
640 GOTO 610
650 IF CH$ = "Y" THEN RETURN
660 PRINT "TYPES OF TEETH :"
670 PRINT "  (1) CUT OR MILLED":TT$(1) = "CUT / MILLED"
680 PRINT "  (2) HOBBED OR SHAPED":TT$(2) = "HOBBED / SHAPED"
690 PRINT "  (3) HIGH PRECISION OR GROUND":TT$(3) = "GROUND"
700 INPUT "INPUT TYPE OF TEETH";TT:IF TT<1 OR TT>3 OR TT<>INT(TT) THEN 700
710 IF CH$ = "Y" THEN RETURN
720 INPUT "RELIABILITY DUE TO FATIGUE (%)";RELP:REL = RELP / 100
730 IF CH$ = "Y" THEN RETURN
740 INPUT "RELIABILITY DUE TO SURFACE DURABILITY (%)";RELSP:RELS = RELSP / 100
750 IF CH$ = "Y" THEN RETURN
760 INPUT "EXPECTED LIFETIME (hours)";HOUR
770 COL = N * 60 * HOUR
780 IF CH$ = "Y" THEN RETURN
790 INPUT "TEMPERATURE OF OPERATION (Celsius)";TEMP
800 IF CH$ = "Y" THEN RETURN
810 PRINT "DESCRIPTION OF SHOCK IN GEAR SYSTEM :"
820 PRINT "  (1) UNIFORM":PS$(1) = "UNIFORM":DMS$(1) = "UNIFORM"
830 PRINT "  (2) MODERATE":PS$(2) = "MODERATE":DMS$(2) = "MODERATE"
840 PRINT "  (3) HEAVY":PS$(3) = "HEAVY":DMS$(3) = "HEAVY"
850 IF QU = 11 THEN 890
860 INPUT "INPUT TYPE OF SHOCK AT SOURCE OF POWER";PS1
870 IF PS1 < 1 OR PS1 > 3 OR PS1 <> INT(PS1) THEN 860
880 PS = PS1 - 1:IF CH$ = "Y" THEN RETURN
890 INPUT "INPUT TYPE OF SHOCK ON THE DRIVEN MACHINERY";DMS1
900 IF DMS1 < 1 OR DMS1 > 3 OR DMS1 <> INT(DMS1) THEN 890
910 DMS = DMS1 - 1:IF CH$ = "Y" THEN RETURN
920 CLS
930 PRINT "CHARACTERISTIC OF THE SUPPORT :"
```

```
940 PRINT "   (1) ACCURATE MOUNTING":CSP$(1) = "ACCURATE"
950 PRINT "   (2) AVERAGE MOUNTING":CSP$(2) = "AVERAGE"
960 PRINT "   (3) BELOW AVERAGE MOUNTING":CSP$(3) = "BELOW AVERAGE"
970 INPUT "CHOOSE TYPE OF SUPPORT";CSUPP
980 IF CSUPP < 1 OR CSUPP > 3 OR CSUPP <> INT(CSUPP) THEN 970
990 IF CH$ = "Y" THEN RETURN
1000 INPUT "YIELD STRENGTH OF PINION (kpsi)";SYK:SY = SYK * 1000
1010 IF CH$ = "Y" THEN RETURN
1020 INPUT "ULTIMATE STRENGTH OF PINION (kpsi)";SUTK:SUT = SUTK * 1000
1030 IF CH$ = "Y" THEN RETURN
1040 INPUT "BRINELL HARDNESS OF PINION";HB
1050 IF CH$ = "Y" THEN RETURN
1060 INPUT "YOUNG'S MODULUS OF PINION (Mpsi)";EPM:EP = EPM * 1000000!
1070 IF CH$ = "Y" THEN RETURN
1080 INPUT "POISSON'S RATIO FOR PINION";UP
1090 IF CH$ = "Y" THEN RETURN
1100 INPUT "YOUNG'S MODULUS OF GEAR (Mpsi)";EGM:EG = EGM * 1000000!
1110 IF CH$ = "Y" THEN RETURN
1120 INPUT "POISSON'S RATIO FOR GEAR";UG:IF CH$ = "Y" THEN RETURN
1130 INPUT "(U)NIDIRECTIONAL OR (B)IDIRECTIONAL DRIVE";GD$:IF LEN(GD$) = 0 THEN
1130
1140 GD$ = LEFT$(GD$,1):IF GD$ <> "U" AND GD$ <> "B" THEN 1130
1150 IF CH$ = "Y" THEN RETURN
1160 GOTO 150
1170 CLS:PO = P:NTO = NT
1180 PRINT "INPUT EXECUTION PARAMETERS":PRINT
1190 INPUT "INITIAL GUESS FOR PITCH (MIN. = 2)";P:IF P < 2 THEN 1190
1200 INPUT "PITCH INCREMENT";IP
1210 INPUT "MAXIMUM ALLOWABLE PITCH (MAX & DEFAULT = 200)";PMAX
1220 IF PMAX < 2 OR PMAX > 200 THEN PMAX = 200
1230 INPUT "MAXIMUM NUMBER OF TEETH ON PINION (MAX & DEFAULT IS 300)";NTMAX
1240 NTMAX = INT(NTMAX):IF NTMAX = 0 OR NTMAX > 300 THEN NTMAX = 300
1250 DMAX = NTMAX / 2:VMAX = PI * DMAX * N / 12
1260 DMAXG = DMAX * MG:CDMAX = (DMAX + DMAXG) / 2
1270 INPUT "ALL THREE SAFETY FACTORS ABOVE ONE (DEFAULT = Y)";YFS$
1280 IF LEN(YFS$) > 0 THEN YFS$ = LEFT$(YFS$,1)
1290 PRINT:PRINT "MAXIMUM POSSIBLE PITCH DIAMETER OF PINION :";DMAX;"in"
1300 PRINT "MAXIMUM POSSIBLE PITCH DIAMETER OF GEAR :";DMAXG;"in"
1310 PRINT "MAXIMUM POSSIBLE CENTER DISTANCE :";CDMAX;"in"
1320 PRINT "MAXIMUM POSSIBLE LINE VELOCITY :";VMAX;"fpm"
1330 PRINT:INPUT "ARE THESE CONDITIONS SATISFACTORY";QMAX$
1340 IF QMAX$ <> "N" THEN CLS:GOTO 1360
1350 CLS:PRINT "ENTER NEW EXECUTION PARAMETERS":GOTO 1190
1360 GOSUB 3010
1370 REM  SET FLAGS EQUAL TO ZERO
1380 FLAG1 = 0:FLAG2 = 0:FLAG3 = 0
1390 ON Q GOTO 1400,1480,1610
1400 REM  YIELD STRENGTH
```

```
1410 INPUT "STATIC LOAD SAFETY FACTOR";SFY
1420 SIGMAP = SY / SFY
1430 GOSUB 1820
1440 F = WT * P / (KV * Y * SIGMAP)
1450 GOSUB 1900
1460 IF FLAG$ = "YES" THEN 1430
1470 GOTO 1730
1480 REM  FATIGUE LOADING
1490 INPUT "FATIGUE LOAD SAFETY FACTOR";SFF
1500 GOSUB 1820
1510 GOSUB 2350
1520 FG = 3 * PI / P
1530 GOSUB 2560
1540 NG = KO * KM * SFF
1550 SIGMAPF = SE / NG
1560 F = WT * P / (KV * SIGMAPF * J)
1570 IF ABS(F - FG) > .001 THEN FG = F: GOTO 1530
1580 GOSUB 1900
1590 IF FLAG$ = "YES" THEN 1500
1600 GOTO 1730
1610 REM  SURFACE DURABILITY
1620 INPUT "SURFACE DURABILITY SAFETY FACTOR";SFS
1630 GOSUB 2690
1640 GOSUB 1820
1650 FG = 3 * PI / P
1660 GOSUB 2560
1670 NG = KO * KM * SFS
1680 WTP = NG * WT
1690 F = (CPS / SH)^2 * WTP / (KV * D * I)
1700 IF ABS(F - FG) > .001 THEN FG = F:GOTO 1660
1710 GOSUB 1900
1720 IF FLAG$ = "YES" THEN 1640
1730 REM  ASK FOR ANOTHER DESIGN OR END
1740 IF FIND$ = "YES" THEN 1770
1750 PRINT:PRINT:PRINT
1760 PRINT "   SORRY, NO SUITABLE FACE WIDTH FOUND."
1770 PRINT
1780 INPUT "DO YOU WISH FOR ANOTHER DESIGN";Q$
1790 IF LEFT$(Q$,1) = "Y" THEN P = PO:NT = NTO:GOTO 10
1800 PRINT:PRINT
1810 PRINT "THANK YOU FOR USING THIS PROGRAM":FOR COUNT = 1 TO 1000:NEXT COUNT:C
LS:END
1820 REM  SUBROUTINE FOR COMMON FACTORS
1830 D = NT / P
1840 V = PI * D * N / 12
1850 WT = 33000! * H / V
1860 IF TT = 1 THEN KV = 1200 / (1200 + V): GOTO 1890
1870 IF TT = 2 THEN KV = 50 / (50 + SQR(V)): GOTO 1890
```

```
1880 KV = SQR(78 / (78 + SQR(V)))
1890 RETURN
1900 REM  SUBROUTINE FOR COMPARISON
1910 FIND$ = "YES"
1920 P3 = 3 * PI / P:P5 = 5 * PI / P
1930 IF F >= P3 AND F <= P5 THEN GOSUB 2830:GOTO 2070
1940 IF F < P3 THEN P = P + IP:FLAG1 = 1:GOTO 1960
1950 IF F > P5 THEN P = P - IP:FLAG2 = 2
1960 FLAG3 = FLAG1 + FLAG2
1970 IF FLAG3 = 3 THEN FLAG3 = 0:GOTO 2020
1980 IF F <= 0 THEN 2020
1990 IF P > PMAX OR P < 2 THEN 2020
2000 FLAG$ = "YES"
2010 RETURN
2020 P = P0:FLAG1 = 0:FLAG2 = 0:FLAG3 = 0
2030 NT = NT + 1:FLAG$ = "YES"
2040 IF NT > NTMAX THEN FLAG$ = "NO":FIND$ = "NO":RETURN
2050 GOSUB 3010
2060 RETURN
2070 IF YFS$ = "N" THEN 2100
2080 IF SFY >= 1 AND SFF >= 1 AND SFS >= 1 THEN 2100
2090 FLAG$ = "YES":Q$ = "Y":GOTO 2320
2100 REM  PRINT RESULTS
2110 CLS
2120 PRINT
2130 PRINT "PINION GEAR :"
2140 PRINT
2150 PRINT "PITCH =";P;"TEETH / IN"
2160 PRINT "NUMBER OF TEETH =";NT
2170 PRINT "PITCH DIAMETER =";D;"IN"
2180 PRINT "LINE VELOCITY =";V;"FPM"
2190 PRINT "LOAD =";WT;"LBF"
2200 PRINT "FACE WIDTH =";F;"IN"
2210 PRINT "MAXIMUM FACE WIDTH =";P5;"IN"
2220 PRINT "MINIMUM FACE WIDTH =";P3;"IN"
2230 PRINT:PRINT
2240 PRINT "                        SAFETY FACTOR"
2250 PRINT
2260 PRINT " STATIC LOADING :       ";SFY
2270 PRINT " FATIGUE LOADING :      ";SFF
2280 PRINT " SURFACE DURABILITY :   ";SFS
2290 PRINT
2300 REM  SEE IF USER DESIRE ANOTHER DESIGN
2310 INPUT "DO YOU WISH TO TRY ANOTHER SIZE";Q$
2320 IF LEFT$(Q$,1) = "Y" AND FLAG1 = 1 THEN P = P + IP:FLAG$ = "YES":RETURN
2330 IF LEFT$(Q$,1) = "Y" AND FLAG2 = 2 THEN P = P - IP:FLAG$ = "YES":RETURN
2340 FLAG$ = "NO":RETURN
2350 REM  SUBROUTINE FOR FATIGUE STRENGTH FACTORS
```

```
2360 IF SUT <= 200000! THEN SEP = .5 * SUT:GOTO 2380
2370 SEP = 100000!
2380 KA = -1 * (.2 / 170000!) * SUT + .8706
2390 CP = PI / P
2400 IF CP > .3 THEN KB = .869 * CP ^ -.097:GOTO 2420
2410 KB = 1
2420 IF REL = .5 THEN KC = 1:GOTO 2490
2430 IF REL <= .9 THEN KC = .897:GOTO 2490
2440 IF REL <= .95 THEN KC = .868:GOTO 2490
2450 IF REL <= .99 THEN KC = .814:GOTO 2490
2460 IF REL <= .999 THEN KC = .753:GOTO 2490
2470 IF REL <= .9999 THEN KC = .702:GOTO 2490
2480 KC = .659
2490 IF TEMP <= 450 THEN KD = 1:GOTO 2510
2500 IF TEMP > 450 THEN KD = 1 - .0058 * (T - 450)
2510 KE = 1
2520 IF GD$ = "B" THEN KF = 1:GOTO 2540
2530 KF = 2 * (SUT / SEP) / ((SUT /SEP) + 1)
2540 SE = KA * KB * KC * KD * KE * KF * SEP
2550 RETURN
2560 REM  SUBROUTINE TO DETERMINE KO, KM
2570 KO = 1! + PS * .25 + DMS * .25
2580 IF DMS = 2 THEN KO = KO + .25
2590 IF FG <= 2 THEN I2 = 1:GOTO 2630
2600 IF FG <= 6 THEN I2 = 2:GOTO 2630
2610 IF FG <= 9 THEN I2 = 3:GOTO 2630
2620 I2 = 4
2630 I1 = CSUPP
2640 KM(1,1) = 1.3:KM(1,2) = 1.4:KM(1,3) = 1.5:KM(1,4) = 1.8
2650 KM(2,1) = 1.6:KM(2,2) = 1.7:KM(2,3) = 1.8:KM(2,4) = 2.2
2660 IF I1 = 3 THEN KM = 2.3
2670 KM = KM(I1,I2)
2680 RETURN
2690 REM  SUBROUTINE FOR SURFACE DURABILITY FACTORS
2700 SC = .4 * HB - 10
2710 IF COL <= 10000 THEN CL = 1.5:GOTO 2750
2720 IF COL <= 100000! THEN CL = 1.3:GOTO 2750
2730 IF COL <= 1000000! THEN CL = 1.1:GOTO 2750
2740 CL = 1!
2750 IF RELS <= .99 THEN CR = .8:GOTO 2780
2760 IF RELS <=.999 THEN CR = 1:GOTO 2780
2770 CR = 1.25
2780 CH = 1:CT = 1
2790 SH = 1000 * CL * CH * SC / (CT * CR)
2800 I = COS(PI * THI / 180) * SIN(PI * THI / 180) * MG / (2 * (MG + 1))
2810 CPS = SQR((PI * ((1-UP^2) / EP + (1-UG^2) / EG))^-1)
2820 RETURN
2830 REM  CHECK OTHER DESIGN CONSIDERATIONS FOR SAFETY FACTOR
```

```
2840 GOSUB 1820
2850 REM STATIC LOAD
2860 SIGMAP = WT * P / (KV * F * Y)
2870 SFY = SY / SIGMAP
2880 REM FATIGUE LOAD
2890 GOSUB 2350
2900 GOSUB 2560
2910 SIGMAPF = WT * P / (KV * F * J)
2920 NG = SE / SIGMAPF
2930 SFF = NG / (KO * KM)
2940 REM SURFACE DURABILITY
2950 GOSUB 2690
2960 GOSUB 2560
2970 WTP = (SH / CPS)^2 * F * KV * D * I
2980 NG = WTP / WT
2990 SFS = NG / (KO * KM)
3000 RETURN
3010 REM  SUBROUTINE TO ENTER LEWIS FORM FACTOR AND GEOMETRY FACTOR
3020 CLS
3030 PRINT "PRESSURE ANGLE =";THI;"DEGREES"
3040 PRINT "NUMBER OF TEETH ON PINION =";NT
3050 NTG = MG * NT
3060 PRINT "NUMBER OF TEETH ON GEAR =";NTG
3070 PRINT
3080 PRINT "FIND Y AND J VALUES FROM TABLES 13-3, 13-5, AND 13-6"
3090 PRINT
3100 PRINT "WARNING : THIS PROGRAM WILL ABORT IF Y OR J EQUALS ZERO"
3110 PRINT
3120 INPUT "INPUT THE LEWIS FORM FACTOR Y";Y
3130 INPUT "INPUT THE GEOMETRY FACTOR J";J
3140 CLS
3150 IF Y = 0 OR J = 0 THEN END
3160 RETURN
```

APPENDIX C

Molding

Mold Strength and Weight

Calculation of wall thickness:

Load = 25 lbf

Strength of Kevlar = 65,000 psi

65000 = 25 / ((outside radius - inside radius) * t)

t = 25 / (6" - 3")*65000

t = 192.3 microinches (minimum)

To allow for deflection and failure due to buckling,

use t = 0.5 inches

Volume of Mold:

V $\approx$ surface area * thickness

V $\approx$ 2 * (12*12) + 4 * (18*12) * thickness

V $\approx$ 1152 square inches * thickness

V $\approx$ 576 in

Mass of Mold:

m = density * V

density = 0.05 lbm/in

m = 28.8 lbm

Mold Permeability

The permeability of the brick cannot be determined without testing actual samples, but assuming it is similar to sludge deposits out of aqueous solutions on earth, the permeability should be about 0.46 Darcy (SI). One Darcy constructed from SI units is about 9.155E-4 Darcy (USCS). This arises simply from units conversions from the formula for permeability given as:

$$k = \frac{\mu \bar{q}_{vr} \Delta s}{\Delta P a}$$

Where

μ = Viscosity

q_{vr} = Volumetric flow rate

Δs = Section Thickness

ΔP = Pressure drop

a = Cross Sectional Area

An equivalent permeability due to capillaries is determined by dimensional analysis.

$$Q = (\nabla P)^a \mu^b A^c \rho^d$$

$$a + b + d = 0$$

$$-2a - b = -1$$

$$-2a - b + 2c - 3d = 3$$

$a = 1$ (from Darcy

$\therefore$ $b = -1$

$c = 2$

$d = 0$

$$Q = \frac{n A^2}{\mu} \nabla P$$

Thus, given a capillary density of 100 holes per square inch,

$r = 0.033$ in.

Derivation of the Governing Differential Equation

for Vapor Diffusion out of the Brick

From Pascal, we have:

$$(1) \quad -\rho \frac{\partial p}{\partial t} = \frac{\mu}{2\pi h g k} \frac{Q}{r} + \frac{\beta}{4\pi^2 h^2 g^2} \frac{Q^2}{r^2}$$

and

$$(2) \quad \frac{1}{r} \frac{\partial Q}{\partial r} = -2\pi m h_g \frac{\partial \rho}{\partial t}$$

Where

$$\rho = \alpha P$$

and

$$\alpha = \frac{\rho_a}{P_a Z(p)}$$

Assume α is approximately constant because for most of the process the water vapor will behave as an ideal gas so Z(p) = 1, and both ρ_a and P_a are constant.

The second term on the right side of equation (1) is between two and three orders of magnitude smaller than the first term as we are dealing with radii above 1 inch and low volumetric flowrates. This term will be neglected and Darcy flow assumed. Darcy flow is governed by the equation:

$$Q = C \nabla P$$

Where C is a constant.

When Darcy flow is assumed, it follows that the volumetric flow rate tends to zero as the pressure gradient approaches zero. Therefore, we can solve the differential equations for pressure to determine the required diffusion time.

With the non-linearity removed, equation (1) becomes:

$$-p \frac{\partial p}{\partial r} = \frac{\mu}{2\pi h g k} \frac{Q}{r}$$

$$-\alpha p \frac{\partial p}{\partial r} = \frac{\mu}{2\pi h g k} \frac{Q}{r}$$

$$Q = \frac{-2\pi h g k \alpha r}{\mu} p \frac{\partial p}{\partial r}$$

$$\frac{\partial Q}{\partial r} = \frac{-2\pi h g k \alpha}{\mu}\left(p \frac{\partial p}{\partial r} + r\left(\frac{\partial p}{\partial r}\right)^2 + r p \frac{\partial^2 p}{\partial r^2}\right)$$

$$\frac{1}{r} \frac{\partial Q}{\partial r} = -\frac{2\pi h g k \alpha}{\mu}\left(\frac{p}{r} \frac{\partial p}{\partial r} + \left(\frac{\partial p}{\partial r}\right)^2 + p \frac{\partial^2 p}{\partial r^2}\right)$$

But from (2)

$$\frac{1}{r} \frac{\partial Q}{\partial r} = -2\pi m h g \frac{\partial \rho}{\partial t} = -2\pi m h g \alpha \frac{\partial p}{\partial t}$$

$$-2\pi m g h \alpha \frac{\partial p}{\partial t} = \frac{-2\pi h g k \alpha}{\mu}\left(\frac{p}{r} \frac{\partial p}{\partial r} + \left(\frac{\partial p}{\partial r}\right)^2 + p \frac{\partial^2 p}{\partial r^2}\right)$$

$$m \frac{\partial p}{\partial t} = \frac{k}{\mu}\left(\frac{p}{r} \frac{\partial p}{\partial r} + \left(\frac{\partial p}{\partial r}\right)^2 + p \frac{\partial^2 p}{\partial r^2}\right)$$

$$\frac{\partial p}{\partial t} = \frac{1}{Z}\left(\frac{p}{r} \frac{\partial p}{\partial r} + \left(\frac{\partial p}{\partial r}\right)^2 + p \frac{\partial^2 p}{\partial r^2}\right)$$

Where

$$Z = \frac{m\mu}{k}$$

While there is no analytical, closed-form solution to this differential equation, it can be solved numerically with the program listed on the following page.

Note that 10 nodes are taken (one at every inch along a radial line). The program was found to be stable only when DT was less than 4/10ths of Z. The program merely implements a standard n umerical

technique. At each step, the new value of pressure is determined, and the process repeats. When a small enough time step is used, the method gives a stable solution to the equation under given initial conditions.

The results of the solution are plotted on the page following the program listing.

APPENDIX D

Water Reclamation

SIMULATION OF MOLD TANK EVACUATION

```
10 REM ****************************************
20 REM
30 REM SIMULATION OF WATER RECLAIMATION SYSTEM
40 REM
50 REM  WRITTEN BY ALAN CHAO FOR ME4182
60 REM
70 REM     DATE: MAY 29, 1986
80 REM
90 REM ****************************************
100 REM
110 REM INITIALIZE VARIABLES
120 REM
130 REM ****************************************
140 K = 1.4
150 MN2 = 28.008
160 KP = (K - 1) / K
170 R = 1545 / MN2
180 INPUT "INITIAL PRESSURE OF MOLD CHAMBER (PSI)";PO
190 INPUT "INITIAL TEMPERATURE OF MOLD CHAMBER (F)";TEMPO
200 TEMPO = TEMPO + 460
210 INPUT "VOLUME OF MOLD CHAMBER (FT^3)";V
220 INPUT "DESIRED TIME FOR EVACUATION (SEC)";TF
230 INPUT "FINAL PRESSURE DESIRED (PSI)";PF
260 S = V * LOG(PO / PF) / TF
270 LPRINT "REQUIRED CAPACITY OF PUMP (FT^3 / SEC) :";S
280 REM ****************************************
290 REM
300 REM              BEGIN SIMULATION
310 REM
320 REM ****************************************
335 LPRINT "TIME","PRESSURE","TEMP","MDOT"
340 FOR TIME = 0 TO TF STEP .01
350 PMOLD = PO * EXP(-S * TIME / V)
360 TEMP = TEMPO * ((PMOLD / PO) ^ KP)
370 RHO = PMOLD * 144 / (R * TEMP)
380 MDOT = RHO * S
390 LPRINT USING "###.###      ";TIME,PMOLD,TEMP,MDOT
400 NEXT TIME
```

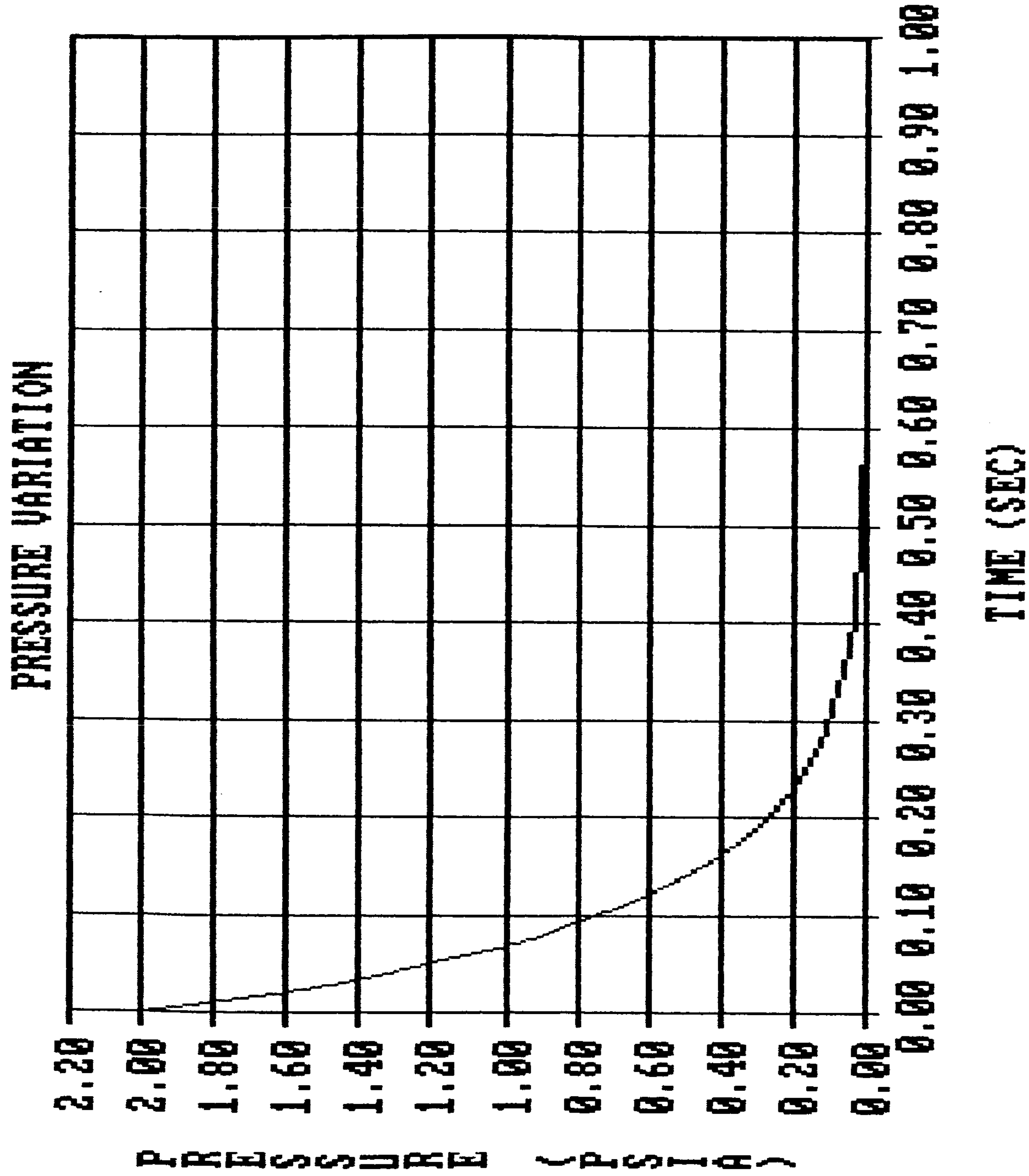
SIMULATION RESULTS

REQUIRED CAPACITY OF PUMP (FT^3 / SEC) : 67.64803

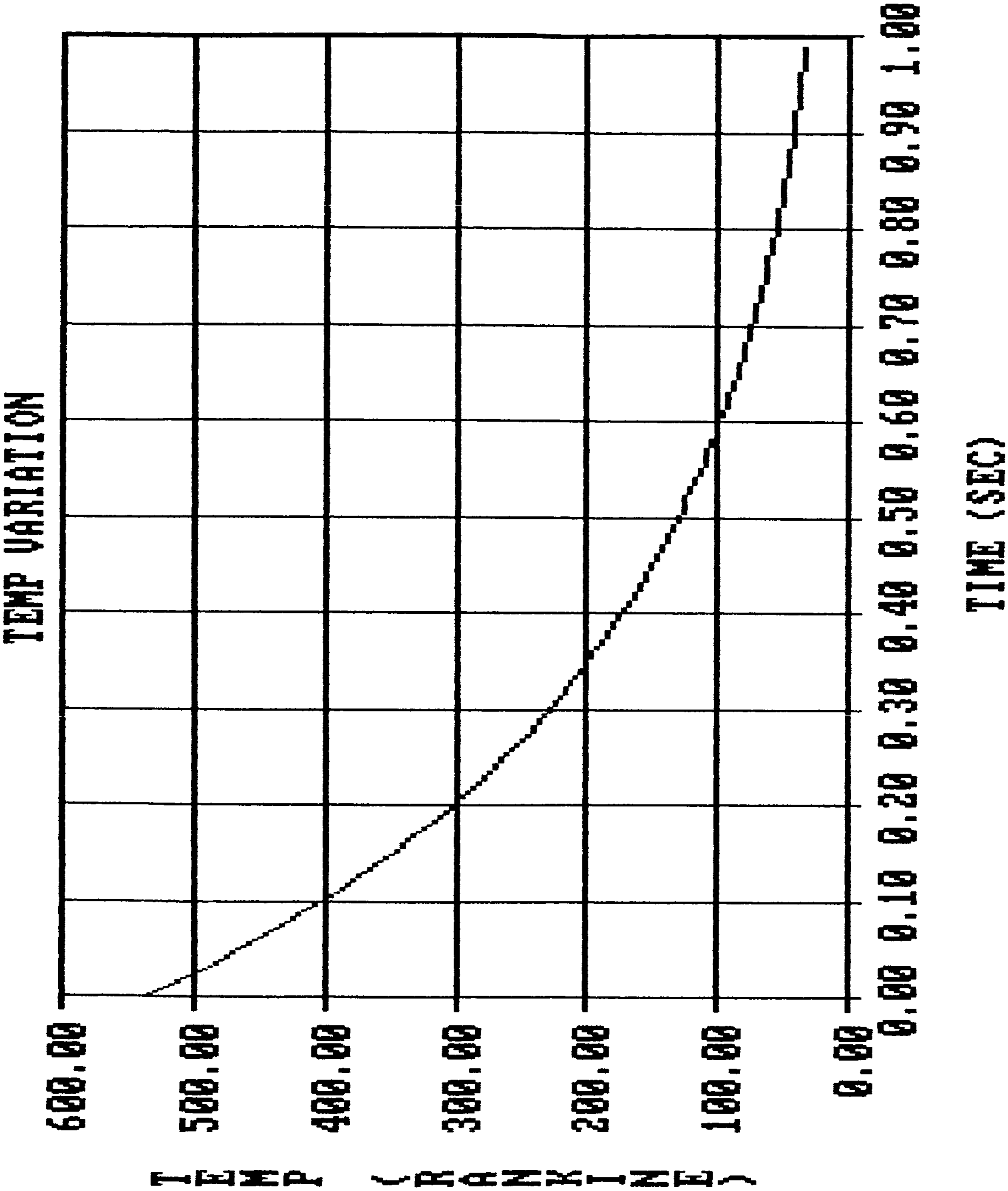
TIME	PRESSURE	TEMP	MDOT
0.000	2.000	537.000	0.658
0.010	1.854	525.464	0.623
0.020	1.718	514.175	0.590
0.030	1.592	503.129	0.559
0.040	1.476	492.321	0.529
0.050	1.368	481.745	0.501
0.060	1.268	471.395	0.475
0.070	1.175	461.268	0.450
0.080	1.089	451.359	0.426
0.090	1.009	441.663	0.403
0.100	0.935	432.175	0.382
0.110	0.867	422.890	0.362
0.120	0.803	413.805	0.343
0.130	0.745	404.916	0.325
0.140	0.690	396.217	0.308
0.150	0.640	387.705	0.291
0.160	0.593	379.376	0.276
0.170	0.549	371.226	0.261
0.180	0.509	363.251	0.248
0.190	0.472	355.448	0.234
0.200	0.437	347.812	0.222
0.210	0.405	340.340	0.210
0.220	0.376	333.028	0.199
0.230	0.348	325.874	0.189
0.240	0.323	318.873	0.179
0.250	0.299	312.023	0.169
0.260	0.277	305.320	0.160
0.270	0.257	298.761	0.152
0.280	0.238	292.342	0.144
0.290	0.221	286.062	0.136
0.300	0.205	279.917	0.129
0.310	0.190	273.903	0.122
0.320	0.176	268.019	0.116
0.330	0.163	262.261	0.110
0.340	0.151	256.627	0.104
0.350	0.140	251.114	0.098
0.360	0.130	245.720	0.093
0.370	0.120	240.441	0.088
0.380	0.111	235.276	0.084
0.390	0.103	230.221	0.079
0.400	0.096	225.275	0.075
0.410	0.089	220.436	0.071
0.420	0.082	215.700	0.067
0.430	0.076	211.067	0.064
0.440	0.071	206.532	0.060
0.450	0.065	202.095	0.057
0.460	0.061	197.754	0.054
0.470	0.056	193.506	0.051
0.480	0.052	189.348	0.049
0.490	0.048	185.281	0.046
0.500	0.045	181.300	0.044
0.510	0.041	177.406	0.041
0.520	0.038	173.594	0.039
0.530	0.036	169.865	0.037
0.540	0.033	166.216	0.035
0.550	0.031	162.645	0.033

0.550	0.031	162.645	0.033
0.560	0.028	159.151	0.031
0.570	0.026	155.732	0.030
0.580	0.024	152.387	0.028
0.590	0.023	149.113	0.027
0.600	0.021	145.910	0.025
0.610	0.019	142.775	0.024
0.620	0.018	139.708	0.023
0.630	0.017	136.707	0.022
0.640	0.015	133.770	0.020
0.650	0.014	130.896	0.019
0.660	0.013	128.084	0.018
0.670	0.012	125.332	0.017
0.680	0.011	122.640	0.016
0.690	0.011	120.005	0.016
0.700	0.010	117.427	0.015
0.710	0.009	114.905	0.014
0.720	0.008	112.436	0.013
0.730	0.008	110.021	0.012
0.740	0.007	107.657	0.012
0.750	0.007	105.344	0.011
0.760	0.006	103.081	0.011
0.770	0.006	100.867	0.010
0.780	0.005	98.700	0.010
0.790	0.005	96.580	0.009
0.800	0.005	94.505	0.009
0.810	0.004	92.475	0.008
0.820	0.004	90.488	0.008
0.830	0.004	88.544	0.007
0.840	0.003	86.642	0.007
0.850	0.003	84.781	0.007
0.860	0.003	82.959	0.006
0.870	0.003	81.177	0.006
0.880	0.002	79.433	0.006
0.890	0.002	77.727	0.005
0.900	0.002	76.057	0.005
0.910	0.002	74.423	0.005
0.920	0.002	72.824	0.004
0.930	0.002	71.260	0.004
0.940	0.002	69.729	0.004
0.950	0.001	68.231	0.004
0.960	0.001	66.765	0.004
0.970	0.001	65.331	0.003
0.980	0.001	63.927	0.003
0.990	0.001	62.554	0.003
1.000	0.001	61.210	0.003

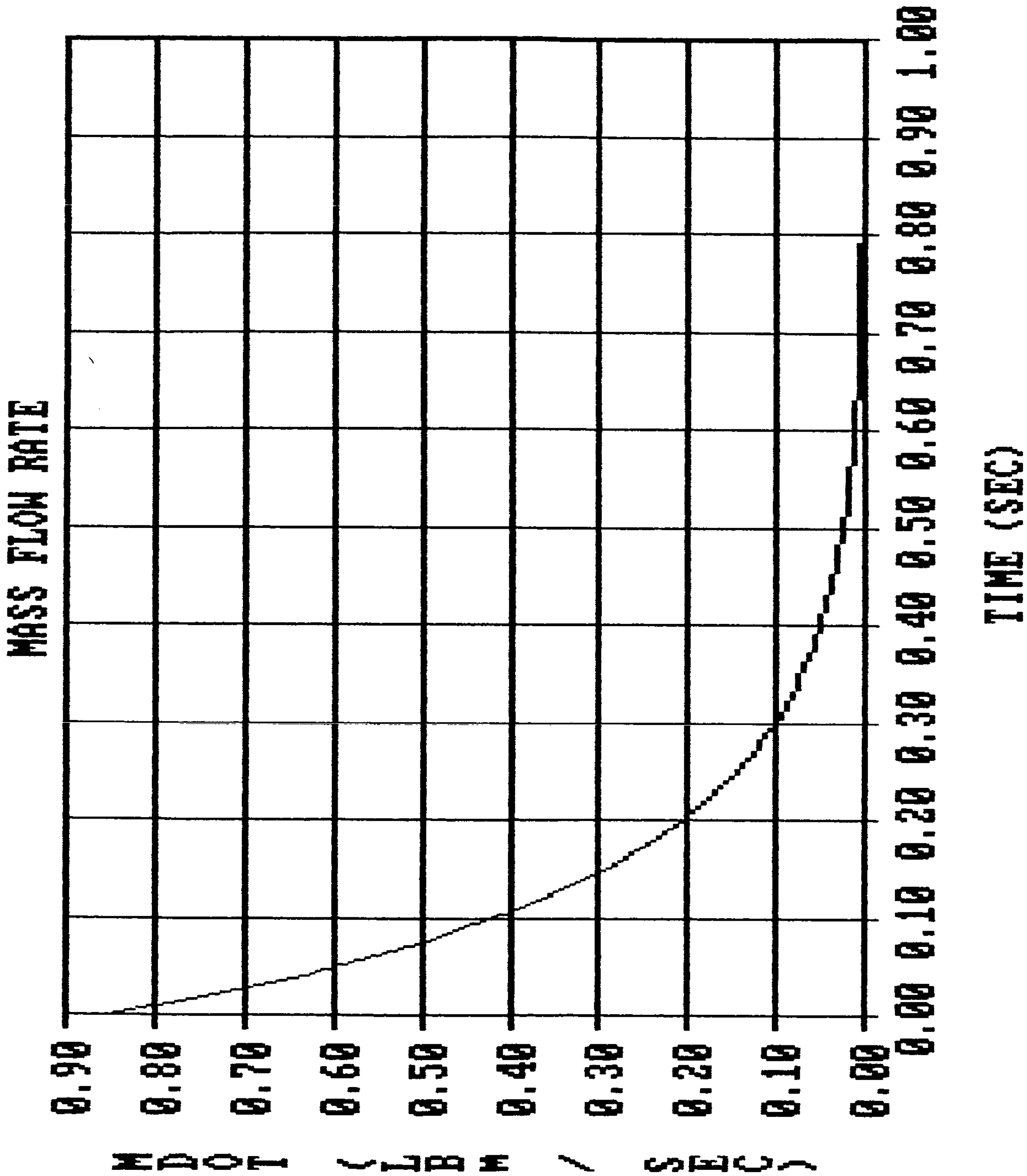
PRESSURE VARIATION IN MOLD CHAMBER



TEMPERATURE VARIATION IN MOLD CHAMBER



MASS FLOW RATE OF PROCESS



CALCULATIONS:

PRESSURE TANKS: $\underset{\text{(Hoop Stress)}}{\sigma} = \dfrac{Pd_i}{2t} = \dfrac{P(d_o - 2t)}{2t}$ (for cyl.) , $\sigma = \dfrac{P(d_o - 2t)}{4t}$ (for sphere)

MOLD CHAMBER: (Cylinder)

For $t = .1$ inch : $\sigma = \dfrac{2\,psi\,(24\,in - .2\,in)}{.2\,in} = 238\,psi$

S_y for A91100 Aluminum is 5 Kpsi

$\therefore\ n = \dfrac{S_y}{\sigma} = \dfrac{5000\,psi}{238\,psi} = 21.0$

Nitrogen Holding tank: (sphere)

For $t = .1$ inch : $\sigma = \dfrac{6.24\,psi\,(24\,in - .2\,in)}{.4\,in} = 371\,psi$

$\therefore\ n = \dfrac{S_y}{\sigma} = \dfrac{5000\,psi}{371\,psi} = 12.4$

Water Holding tank:

For $t = .1$ inch : $\sigma = \dfrac{2\,psi\,(12\,in - .2\,in)}{.4\,in} = 350\,psi$

$n = \dfrac{S_y}{\sigma} = \dfrac{5000\,psi}{350\,psi} = 13.5$

Water Pump Rates:

Need to pump .108 cu. ft of water at a total head of 7 ft. in 1 minutes

need flow rate of $\frac{.108 \text{ cu. ft}}{1 \text{ min}} \cdot \frac{.2642 \text{ gal}}{.0353 \text{ ft}^3} \cdot \frac{60 \text{ min}}{1 \text{ hr}} = 48.5 \text{ GPH} \approx 50 \text{GPH}$

Nitrogen Bleed-OFF Rates:

Need to Bleed .00309 lb-mole of Nitrogen to mold chamber in 4 minutes

$\text{mass} = 28.0 \frac{\text{lbm}}{\text{lb-mole}} \cdot .00309 \text{ lb-mole} = .0865 \text{ lbm}$

$\dot{m} = \frac{.0865 \text{ lbm}}{240 \text{ sec}} = 3.61 \times 10^{-4} \text{ lbm/sec}$ (on the average)

Vacuum Pump System

From Simulation Capacity is 67cfs or 70cfs

From Warring:

Oil-sealed rotary pump require 1/8 HP to obtain 70cfs at a pressure difference of .450 psia

Mechanical booster pump requires 1/6 HP to obtain 70cfs at a pressure difference of 5.50 psia

∴ total pump power required is $1/6 + 1/8$ HP = .291 Hp.

Smallest motor is 1/3 Hp to provide the .291 Hp.

Pipe Connections:

Use flange type mounts with 4" ID pipes

Design for 5 Bolts Standard grade 5

$$F_{total} \cong 2\rho QV = 2(6.75 \times 10^{-5} \text{ slugs}/ft^3)(70.00\ ft^3/sec)(7.75\ ft/sec)$$
$$= 7.08\ lbf$$

$$F@ = \frac{7.08\ lbf}{5\ bolt} = 1.42\ lbf/bolt$$

$$\sigma = F/A \implies A = F/\sigma = \pi r^2$$

$$r = \sqrt{F/\pi\sigma}$$

Use a factor of safety of 3

$$r = \sqrt{\frac{3F}{\pi\sigma}} = \sqrt{\frac{3(1.42\ lbf)}{\pi(30,000\ lbf/in^2)}} = .0067"$$

$$d = .0134"$$

bolt is too small!

$\therefore$ use 5 - 1/4" grade 5 bolts.

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RECORD OF INVENTION - Part I

This is an important legal document. Read instructions carefully before filling in data.

PROJECT NO. 5

CONTRACT NO. N/A

RECOMMENDED SECURITY CLASSIFICATION none

REC. OF INV. NO.

1. NAME OF INVENTOR: YVETTE CHRISTINE LUPIEN — POSITION: GROUP LEADER

2. DEPARTMENT OR DIVISION: School of Mechanical Engineering

3. DATES OF EMPLOYMENT: student - Sept. 1982 - June 1986

4. PRESENT ADDRESS (No. Street, City, County, State): GA. TECH P.O. BOX 30894 Atlanta, GA 30313 — TELEPHONE: (404) 676-0072 — PERMANENT OR UNTIL: June 14, 1986

5. PERMANENT ADDRESS (No. Street, City, County, State): 12210 Christen Ct. Tampa, Hillsborough, Florida — TELEPHONE: (813) 935-8028

6. NAMES (S) AND ADDRESS (ES) OF CO-INVENTORS (If any): Jan Arnette; Russell Creecy; Alan Chao; Foster Finley; Stephen Fuks; Richard D. Malone; David Smith = ALL AVAILABLE THROUGH: Ga. Tech P.O. Box 31070 Atlanta, GA 30313

7. DESCRIPTIVE TITLE OF INVENTION: BRICK MOULDING APARATUS FOR LUNAR APPLICATIONS

8. LIST DRAWINGS, SKETCHES, PHOTOS, REPORTS, DESCRIPTIONS, NOTEBOOK ENTRIES, ETC. WHICH SHOW OR DESCRIBE INVENTION: 1) Report to School of Mechanical Engineering c/o J. W. Brazell

9. EARLIEST DATA AND PLACE INVENTION WAS CONCEIVED (Brief outline of circumstances): Process to make bricks described by Mr. James W. Brazell on March 25

10. DATE AND PLACE OF FIRST SKETCH, DRAWING OR PHOTO: May 22nd 1986, Price Gilbert Memorial Library

11. DATE AND PLACE OF FIRST WRITTEN DESCRIPTION: May 29th, 1986, Price Gilber Memorial Library

12. DISCLOSURE OF INVENTION TO OTHERS

NAME, TITLE AND ADDRESS	FORM OF DISCLOSURE	DATE AND PLACE OF DISCLOSURE	WAS SIGNATURE OBTAINED (YES OR NO)
J.W. Brazell, Lecturer, 225 NORTH AVE. Atlanta, GA 30332	written report	June 3 1986, Ga. Tech	NO

12.A IMPORTANT - HAVE ANY PUBLICATIONS OR REPORTS BEEN MADE ON THIS INVENTION? Yes, a report describing the machine has been compiled.

13. DATE AND PLACE OF COMPLETION OF FIRST OPERATING MODEL OR FULL SIZE DEVICE: Not Applicable

14. PRESENT LOCATION OF MODEL: none

15. DATE, PLACE, DESCRIPTION AND RESULTS OF FIRST TEST OR OPERATION: none

16. NAMES AND ADDRESSES OF WITNESSES OF FIRST TEST

none

17. DATE, PLACE, DESCRIPTION AND RESULTS OF LATER TESTS (name witnesses)

None

18. IDENTIFY RECORDS OF TESTS AND GIVE PRESENT LOCATION OF RECORDS

none

19. PRIOR REPORTS OR RECORDS OF INVENTION TO WHICH INVENTION IS RELATED

ME4182, Winter 1986 report on process to manufacture bricks on Lunar surface.

20. OTHER KNOWN CLOSELY RELATED PATENTS, PATENT APPLICATIONS AND PUBLICATIONS

PATENT OR APPLICATION NO.	DATE	TITLE OF INVENTION OR PUBLISHED ARTICLE	NAME OF PUBLICATION
none			

21. EXTENT OF USE: PAST, PRESENT AND CONTEMPLATED (Give dates, places and other pertinent details)

not currently in use

22. DETAILS OF INVENTION HAVE BEEN RELEASED TO THE FOLLOWING COMPANIES OR ACTIVITIES

NAME AND ADDRESS	INDIVIDUAL OR REPRESENTATIVE	CONTRACT NO.	DATE
GA. Tech 225 North Ave. Atl. GA 30332	J.W. Brazell		6/3/86

SIGNATURE OF INVENTOR Yvette C. Lupien DATE 6/2/86

RECORD OF INVENTION - Part II

(Attach to Record of Invention Part I)

REC. OF INV. NO. ________

This Disclosure of Invention should be written up in the inventor's own words and generally should follow the outline given below. Sketches, prints, photos and other illustrations as well as reports of any nature in which the invention is referred to, if available, should form a part of this disclosure and reference can be made thereto in the description of construction and operation.

INVENTORS NAME(S) Yvette Christine Lupien, (and Others)

TITLE OF INVENTION Brick Moulding Apparatus for Lunar Applications

For answers to following questions use remainder of sheet and attach extra sheets if necessary.

3. GENERAL PURPOSE OF INVENTION. STATE IN GENERAL TERMS THE OBJECTS OF THE INVENTION.
4. DESCRIBE OLD METHOD(S) IF ANY, OF PERFORMING THE FUNCTION OF THE INVENTION.
5. INDICATE THE DISADVANTAGES OF THE OLD MEANS OR DEVICE(S).
6. DESCRIBE THE CONSTRUCTION OF YOUR INVENTION, SHOWING THE CHANGES, ADDITIONS AND IMPROVEMENTS OVER THE OLD MEANS OR DEVICES
7. GIVE DETAILS OF THE OPERATION IF NOT ALREADY DESCRIBED UNDER 6.
8. STATE THE ADVANTAGES OF YOUR INVENTION OVER WHAT HAS BEEN DONE BEFORE.
9. INDICATE ANY ALTERNATE METHODS OF CONSTRUCTION.
10. IF A JOINT INVENTION, INDICATE WHAT CONTRIBUTION WAS MADE BY EACH INVENTOR.
11. FEATURES WHICH ARE BELIEVED TO BE NEW.
12. AFTER THE DISCLOSURE IS PREPARED, IT SHOULD BE SIGNED BY THE INVENTOR(S), AND THEN READ AND SIGNED AT THE BOTTOM OF EACH PAGE BY TWO WITNESSES USING THE FOLLOWING STATEMENT:

"DISCLOSED TO AND UNDERSTOOD BY ME THIS 2 DAY OF June 1986
SIGNATURE ______________________________."

3). Manufacture Bricks out of extraterrestrial material Lignosulfanate and H_2O on Lunar surface

4). mix three substrates, mold into desired shape, ~~vacuum~~ evacuate moisture.

5) no mechanism was capable of this function.

6). Complete description of machine and operational requirements are given in report.

8). Impementation of device would yeild functioning machine

9) none

10). group participation

11). mould chamber

Yvette C. Lupien
INVENTOR
June 2 1986

Disclosed to and understood by me on this 2 day of June 1986
Russell [signature]
WITNESS

Disclosed to and understood by me on this 2 day of June 1986
[signature]
WITNESS